THE STRATIGRAPHY AND SUB-CARSE MORPHOLOGY OF AN AREA ON THE NORTHERN SIDE OF THE RIVER FORTH BETWEEN THE LAKE OF MENTEITH AND KINCARDINE-ON-FORTH

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PREFACE

For many years now, the flat, low-lying land that extends up the Forth valley for 30-40 km from the Grangemouth-Kincardine area, has been of considerable interest to a variety of people, including geographers, historians, naturalists and agriculturalists. At different times, some groups have been more active in their investigations than others, but the net result has been an accumulation of literature on almost every aspect of these "carselands", as they are called, from lists of marine shells found in the carse-clay to the stories of the agricultural achievements of the "moss-lairds" of Blairdrummond.

In all this work, occasional reference may be found to the deposits underlying the carse-clay. Although not particularly numerous and often low in information value, these references give the first indications of a story that is in many ways more interesting than that of the carse itself, for recent investigation has shown that beneath the carse-clay lies a complete landscape, buried by the deposits of the Postglacial transgression.

The purpose of the present study is to examine the extent and nature of the buried landscape and to attempt an explanation of its various facets. Major elements of this landscape have been described as "buried raised beaches" and this terminology itself requires some explanation. Perhaps it would be technically more accurate to refer to these features as "buried raised estuarine deposits" due to their location in a former estuary of the Forth, but such a term is rather cumbersome. At the same time, the carse is commonly considered to be a major expression of the Postglacial "raised beach" sequence, although the carse-clay is mainly estuarine in origin. Thus there is a precedent for the usage and the term "buried raised beach" is employed throughout the thesis.

To place the present work in perspective, it should be noted that it is closely related to the work of J.B. Sissons and D.E. Smith on Late and Postglacial events -- particularly sea-level changes -- in the Forth valley and is linked to other studies of the same period in south-east Scotland carried out in recent years in the Department of Geography of the University of Edinburgh.

In the preparation of this thesis the writer has been aided by numerous people. He wishes particularly to express his gratitude to Dr. J.B. Sissons of the Department of Geography, Edinburgh University for his advice and encouragement throughout and his constructive criticism during the very important final stages of the work. He also wishes to acknowledge the very considerable help of Mr. Ian Kemp and Mrs. Patricia Kemp during the period of fieldwork and collection of data. At that time also, financial aid was provided by the Science Research Council, while the farmers and landowners of the carse allowed access to their property and companies and local authorities provided commercial borehole information. All of this is gratefully acknowledged.

The writer is also indebted to all who helped in the final preparation of the thesis, including Mrs. Marjorie Cameron and Mr. R. Cornell and especially Miss Elizabeth Wear who spent long hours carefully typing the various drafts and final copy. He also takes this opportunity to record his thanks to his wife for her encouragement and patience throughout. Finally, acknowledgements are due to the University of Edinburgh and Lakehead University for the materials and facilities they have provided.

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ABSTRACT

In an area on the northern side of the River Forth, between the Lake of Menteith and Kincardine-on-Forth, the stratigraphy of the carselands was investigated by hand boring, the results being augmented from commercial borehole records. From this, the morphology of the sub-carse deposits was determined and presented in maps and cross-sectional diagrams, for which heights had been obtained by accurate levelling. In addition, samples of the sub-carse deposits were subjected to laboratory analysis.

An examination of the evidence from these sources indicates a landscape, buried beneath the carse, consisting of areas of fine marine sediments forming raised beaches and areas of coarser sand and gravel. In the west, between the Menteith Moraine and Blair-drummond, fine marine sediments predominate and on the basis of variations in colour, composition and altitude they have been divided into three beaches, named the High, Main and Low Buried Raised Beaches. The beaches are closely associated with the Menteith out-wash and the buried valleys of the Forth and its tributaries.

At Blairdrummond, the buried beaches end against the Teith outwash and are absent, except for small patches, as far as Stirling. They are replaced by a large asymmetrical fan of sand and gravel that originated largely as fluvioglacial material issuing from the Teith valley.

Beyond Stirling, sand and gravel deposits supplied by the Ochil streams and the River Devon are important in the buried landscape, but

all three buried beaches reappear, lying along the face of the Ochils, while in the vicinity of Kincardine-on-Forth a buried gravel layer is present. The latter is a product of marine erosion and includes areas of planated rock and till as well as gravel.

An examination of the morphological and stratigraphical relationships between the features, coupled with palynological and radiocarbon evidence, has allowed the determination of the following sequence of events. Close to 12,000 B.P., sea-level began to rise from a position slightly below present O.D. to reach a relative height of 10.0 m O.D. sometime during the halt of the Loch Lomond Readvance ice at the Menteith Moraine. During the rise, erosion produced the buried gravel layer. With the decay of the ice outwash was deposited at Menteith and also at Blairdrummond, while increased fluvial activity caused the formation or growth of numerous fans along the northern edge of the Forth basin. During this period around 10,300 B.P. the High Buried Beach was produced while later oscillations of sea-level caused the formation of the Main and Low Beaches, at successively lower altitudes, at about 9,500 B.P. and 8,800 B.P. respectively, before a final lowering took place close to 8,500 B.P. and the sea was confined to a relatively narrow estuary. The subsequent Postglacial submergence, reaching a maximum about 5,500 B.P., buried the earlier features beneath a layer of carse-clay.

Relationships between these events, local isostatic changes and world-wide eustatic changes were examined, rates of uplift being calculated and shoreline diagrams being produced. Uplift in the Forth fits presently accepted patterns, but the shoreline diagrams indicate a situation, as yet not recognized in other parts of

Scotland, in which variations in gradient take place along tilted shorelines. It is suggested that the search for features equivalent to the buried beaches in other parts of Scotland would help to clarify this and other problems associated with the changing positions of land and sea.

CHAPTER I

CERTAIN ASPECTS OF THE HISTORICAL GEOMORPHOLOGY OF THE FORTH VALLEY, WITH PARTICULAR REFERENCE TO THE RAISED BEACHES

There is nothing new in the observation that the seas around Britain have not always kept their "appointed limits". This has been fairly common knowledge for a long time now and seems to have some peculiar fascination for investigators, giving rise to ideas and fashions, as numerous as the sea-level changes from which they have sprung. No doubt the earliest inhabitants of the country were the first to notice and be affected by some of the changes taking place but, unfortunately, were in no position to leave evidence of their observations. Over the years, however, an extensive body of literature has grown up, based on a wide variety of information, from the discovery of human artifacts to the measurement of coastal landforms.

Scotland is particularly rich in this regard and within the country the Forth valley is well to the fore, as any examination of the literature will show. It was this area that gave birth to the concept which dominated the history of shoreline displacement for more than 80 years -- that of the 100 foot, 50 foot, and 25 foot raised beaches of the Geological Survey. Established in 1879 with the publication of Sheet 31 for an area in the vicinity of Falkirk, the many arguments over the presence or absence of this trio have caused the dissipation of tremendous energy. Much of the detail associated with this need not be repeated in the present context and in any case, has been comprehensively covered elsewhere (Sissons, 1962, 1963, 1965, 1967a; Smith, 1965; Walton, 1966). However, the Survey's 25 foot raised beach provides a useful datum from which the present study may proceed.

This raised beach was equated with the carselands of the River Forth, long recognised as being of marine origin from the abundant shells they contained (The Old Statistical Account of Scotland, 1791, Parish of Kincardine). As with similarly situated deposits on the northern shores of the Solway Firth and in the Clyde and Tay estuaries (Fig.I.1), the carselands of the Forth have had a variety of names applied to them. Although the Geological Survey, with its use of the term "25 foot Raised Beach" for the carselands, implied a feature with heights on its surface, at, or closely approximating 25 feet (7.6 m) and therefore virtually horizontal, neither was the case. This was not something that came to light after the Survey's classification of raised beaches, for several investigators prior to 1879 had considered the Forth carselands as a continuous morphological unit rising westwards up the Forth valley. As early as 1848, Chambers, in his "Ancient Sea Margins", had noted the slope of the carse, explaining it as due to removal of sediments in eastern areas when the sea lay at a lower level than it did when it deposited the carse. Later in 1865 and 1871 respectively, Jamieson and Milne-Home recognised the sloping nature of the carse, but these observations were lost in the general acceptance of the Survey classification.

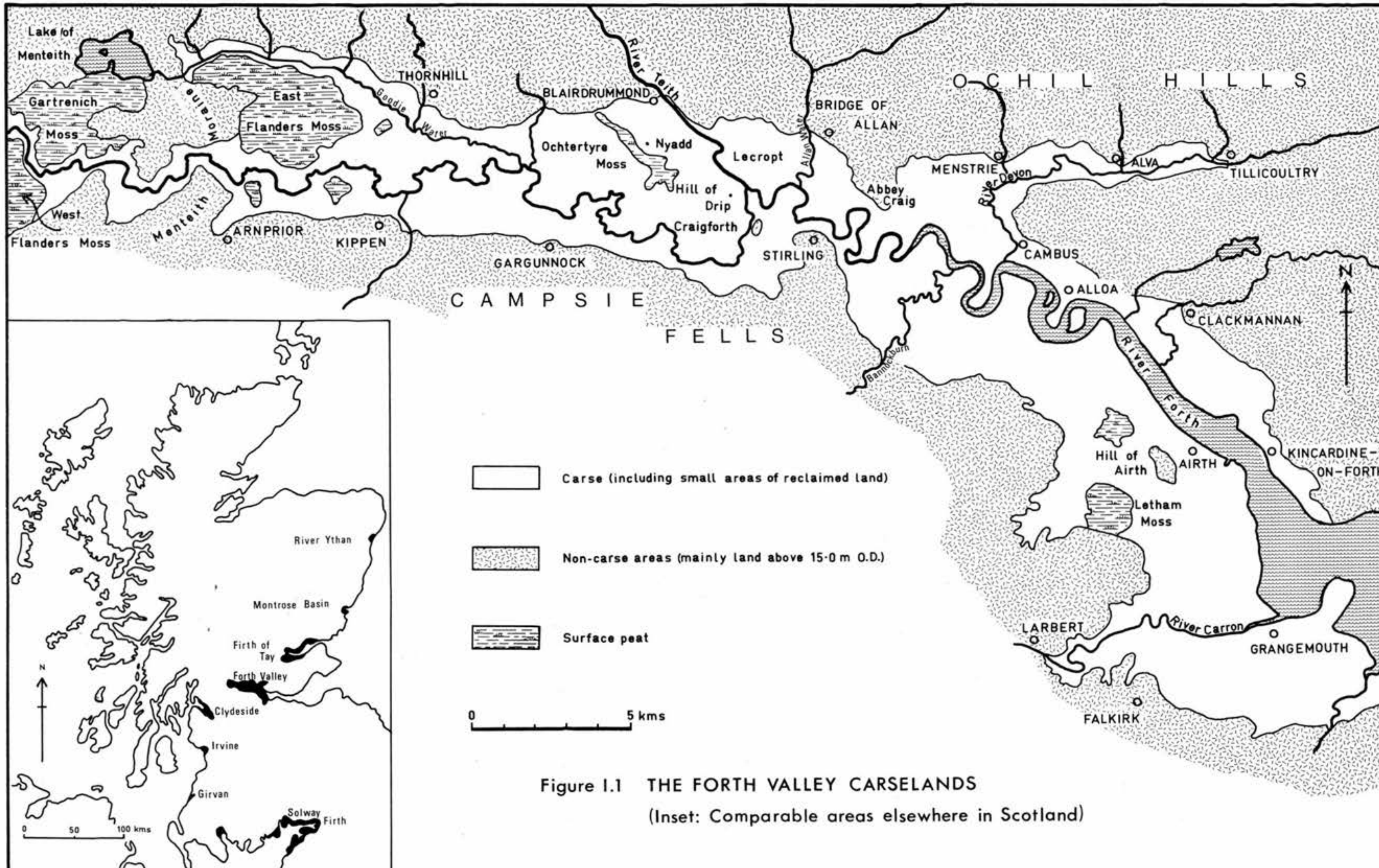


Figure I.1 THE FORTH VALLEY CARSELANDS
(Inset: Comparable areas elsewhere in Scotland)

Perhaps prompted by the difficulty of reconciling the idea of a 25 foot beach with the observable facts, J. Geikie in 1881 divided the carselands into 25 and 50 foot (7.6 and 15.2 m) raised beaches. Considerably later, in 1927, Dinham called them the 50 foot raised beach but by 1959 they had returned, in part at least, to the 25 foot bracket (Read, 1959). As might be expected, considerable confusion was one of the results. Further complications were introduced by archaeologists in the early part of this century when they began to refer to the carse and its stratigraphical equivalents as the "Neolithic Raised Beach". This line was followed up by Movius in 1942 when the abundance of *Littorina littorea* fossils in the so-called 25 foot raised beach prompted him to put forward the term "Littorina Raised Beach" for this feature. Such a trend away from the altitudinal designation of raised beaches can now be seen as a step in the right direction but two major papers in the 1950's helped to retrench the old ideas. In 1955, Charlesworth linked the orthodox interpretation of the Scottish raised beaches with glacial stages and in 1959, Donner, while recognising that the three-fold division did not always match observable facts, thought that for the sake of convenience no change should be made.

Although eminent geologists such as Jamieson and Wright had called the scheme in question it was only in 1962, after Sissons had rejected virtually all the preconceived ideas, that any real headway was made. As already pointed out, this has been fully dealt with elsewhere and need only be considered here as far as it applies to the so-called 25 foot raised beach. The latter term, as with those applied to the other raised beaches, became redundant as soon as accurate altitudinal measurements of the beaches were made and a new terminology was required. The shoreline of the former 25 foot raised beach in the Forth was found to record approximately the highest marine level of Postglacial times. This, together with the widespread nature of the associated deposits, led to its being named the Main Postglacial Shoreline or Beach, depending upon the context in which it was being used.

Following the formation of this raised beach, the level of the sea relative to the land began to fall towards its present position. That this was by no means completely smooth and continuous has been indicated by the presence of an additional three beaches lying lower than the main one. As a result, between Grangemouth and Stirling -- the area in which these lower beaches are best preserved -- a total of four Postglacial raised beaches has been differentiated, while west of Stirling all but the lowest of these have been recognized. In places, separation into different levels was only possible after careful altitudinal measurement, but in others a low, but distinct bluff could be seen marking the change from one beach to the other (Sissons, Smith and Cullingford, 1966; Sissons, 1967a; Smith, 1968).

Measurements along the shorelines of each of these beaches have shown that all slope eastwards with decreasing gradients from the Main Postglacial Beach through the other three (Fig.I.2). A figure of 0.4 feet per mile (0.08 m/km) has been calculated for the former, both north and south of the River Forth (Sissons, 1967a, Smith, 1968). The two middle beaches have produced very similar gradients close to 0.3 feet per mile (0.06 m/km), although on the

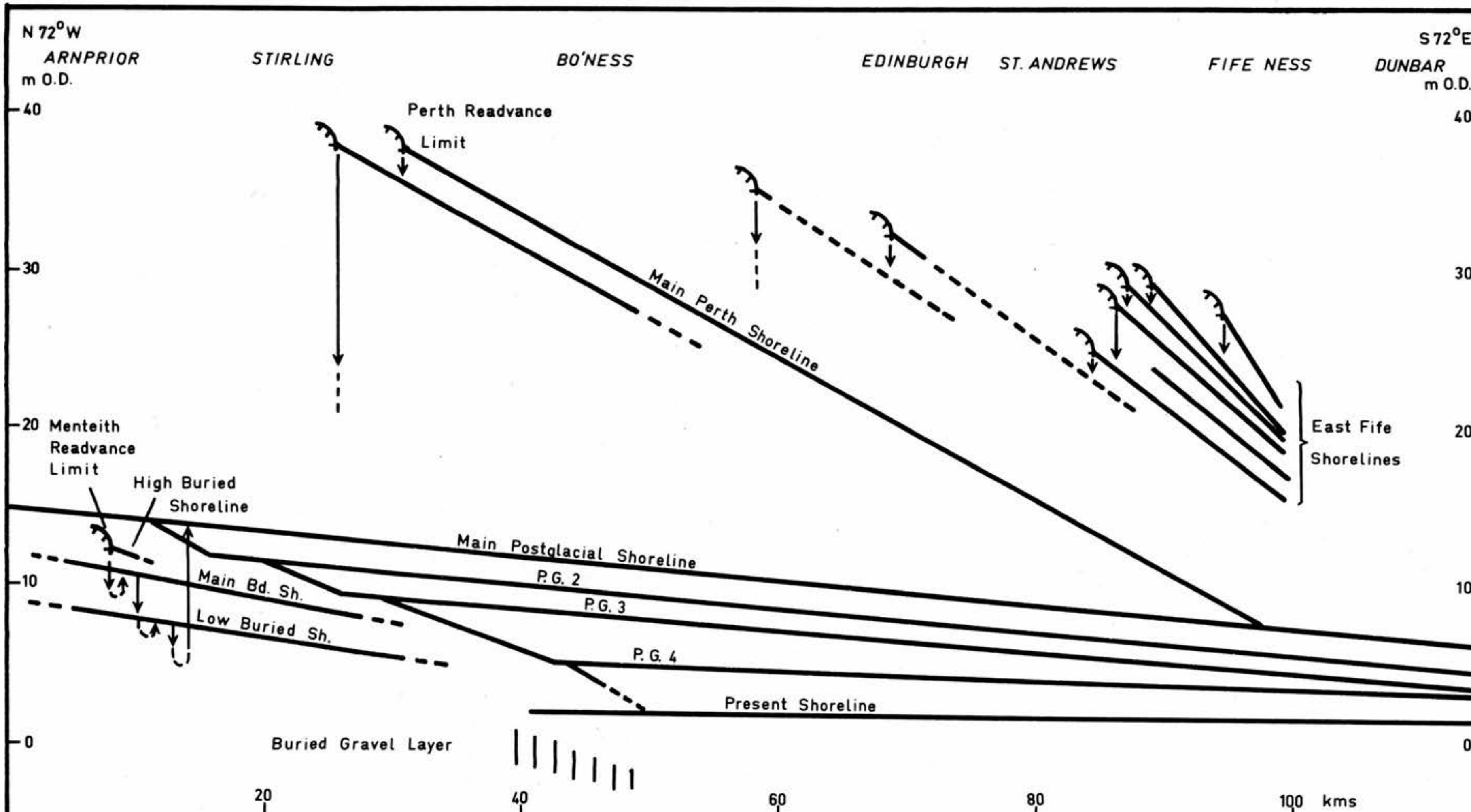


Figure 1.2 The raised shoreline sequence in Southeast Scotland (After Sissons *et al.* 1966.)

north side of the valley Smith has found the figure closer to 0.2 (0.04). In the case of the lowest shoreline, a further discrepancy arises, Smith's gradient value of 0.06 feet per mile (0.01 m/km) being less than half of the 0.17 feet per mile (0.03 m/km) quoted by Sissons.

Followed westwards, each shoreline gradient has been found to increase somewhat as the shoreline merges into the one above, pointing to sedimentation while the sea-level was actually falling as opposed to the times when, with respect to the land, it remained virtually stationary. The presence of occasional, very thin peat beneath the carse-clay of the lowest beach has been taken as indicative of a slight transgression, but as yet it is not known if the second and third Postglacial beaches were similarly formed. Thus, increased investigation makes it obvious that, from a geomorphological point of view, the carselands are much more complicated than was thought even relatively recently.

While all this energy was being expended on the carselands as raised beach deposits, little thought appears to have been given to the landscape that existed before the carse sea flooded over the area, covering some 70-80 square miles with deposits thick enough to completely mask the underlying topography. This did not mean that knowledge of what lay beneath the carse-clay was completely lacking, but the evidence was so limited in quantity, so variable in detail and so widely scattered that only very tentative conclusions could be drawn concerning the sub-carse deposits and their relationship to the overlying clay. The earliest recorded observations are to be found in the Old Statistical Accounts of the parishes that include part of the carse within their boundaries. Many, if not most, of the accounts refer to sections exposed by the Forth as it meandered through the area.

Unfortunately the writers of the Statistical Accounts were usually more interested in natural curiosities than in stratigraphical details. For example, the minister of the parish of Kilmadock or Doune noted trunks of oak trees, up to six feet in diameter, exposed beneath 20 feet of clay in the banks of the Goodie Water, a tributary of the Forth, but neglected to mention whether or not the underlying sediments were exposed. In the neighbouring parish of Kincardine the recorder was somewhat more explicit, writing that the carse "is a rich blue clay, beyond any depth that has been examined, excepting one corner, where a bed of gravel rises near the surface, as it approaches the Teath and dips towards the Forth at a rate of one foot in a hundred". Subsequent investigation by the present writer has shown the gravel to be of considerable extent. The account for Kincardine is one of the more informative, drawing attention to the lack of stones in the carse, and the absence of rock at, or near, the surface, "excepting in the eminences of Craig Forth, the Hill of Dript, and the Nadd, and for a small extent of the bed of the river at the cruives of Craig Forth and again at the Bridge of Dript". This chronicler also went as far as to suggest that the carse had been accumulated by the sea.

Detail such as this, limited though it is by modern standards, is useful, but is the exception rather than the rule. Most writers were content to note the unusual, such as the thick beds of sea-shells, the presence of whale skeletons, or the great thickness of carse-clay before rock was reached. In many places the superficial deposits did not consist entirely of carse-clay, but only in a few cases was any differentiation made. In 1841, the writer of the New Statistical Account for the parish of Logie, in Stirlingshire, pointed out that rock lay at 30 feet (9.1 m) below the surface in the northerly parts of the parish carselands, while in contrast rock-head could not be reached south of Abbey Craig. At the same time in Alloa parish the "carse" clay was said to be up to 90 feet (27.4 m) thick, although it seems certain that the term "carse" was used for almost anything that was not solid rock.

It would seem that the reports of the Statistical Accounts are of limited usefulness in most cases, but, until only recently, they provided the bulk of the information on the sub-carse deposits west of Stirling, where little commercial boring had been carried out.

Due to its flat, low-lying nature linked with the mode and time of formation, the surface of the carse proved an ideal situation for the growth of peat. Eventually peat mosses covered most of the area west of Stirling and certain sites east of the town. Most of this peat has since been removed, but fairly extensive areas still exist in the form of elevated mosses standing out above the surrounding cultivated land. On the north side of the Forth, the largest of these is East Flanders Moss, with smaller patches at Gartrenich, Blairdrummond and Ochtertyre (Fig.I.1). East of the Stirling gap, thin surface peat can be found at the back of the carse, where it abuts against the Ochils, but it seems certain that the eastern carselands did not support peat to the same extent as those farther west.

Where peat exists or has existed in this eastern area, its distribution can be related to the different carse surfaces. On the southern side of the river remnants of peat mosses still survive on the Main Postglacial Raised Beach, but there is no evidence for the presence of peat on the lower three. Compared with this, on the northern side, the Main Postglacial Beach is virtually absent and the peat here seems to have grown on the second highest raised beach, distinguished by Smith (1968) as Postglacial 2. The peat which remains is usually very thin, as in the vicinity of Blairlogie, but in the past it appears to have been as much as 7 feet (2.1 m) thick (The New Statistical Account of Scotland, 1841, Parish of Alva). As on the south of the Forth, there is no indication that peat ever covered the two lowest raised beaches.

During the late eighteenth and early nineteenth centuries great inroads were made into the mosses, hundreds of acres of good land being made available for agriculture. During the clearing operations, which are well described in the Statistical Accounts for Kincardine Parish and in Cadell's "Story of the Forth", many sections must have been exposed. Great ditches into which the peat was thrown, later to be flushed into the River Forth, still cross parts of the carse and although now overgrown with vegetation, sections can be re-exposed without too much trouble. It seems possible that the stratigraphy described for the Blairdrummond area by Jamieson (1865) and Milne-Home (1871), was first seen in one of these ditches.

In what is now regarded as a classic paper, Jamieson used the depositional sequence in the Blairdrummond area, along with sections from Tayside, Montrose Basin, and the mouth of the River Ythan, to establish the relative position of land and sea, in Scotland, in recent geological times. He noted the following section:

5. Surface peat.
4. Carse-clay with whale bones.
3. Peat with remains of trees.
2. Glacial Beds -- including marine beds on till.
1. Sandstone Rock.

From this Jamieson judged that, following the retreat of the ice that had deposited the till, the rising sea-level caused the marine beds to be laid down. With subsequent emergence, trees and peat grew on the newly uncovered ground only to be drowned when the sea-level rose again, depositing the carse-clay. Finally elevation raised the carselands to their present position, allowing the development of the area's great mosses. An essentially similar story had been outlined for the Tay estuary and the adjacent River Earn as early as 1841 by Buist, but it was only with Jamieson's consideration of a number of sites in Eastern Scotland that the broader implications became apparent.

A few years later, Milne-Home, writing about the Blair-drummond area, saw the buried peat as having been drifted into position rather than having accumulated *in situ*. Earlier writers had, however, shown it to be too extensive for this to have been the case and it had been pointed out that trees incorporated in the buried peat had roots penetrating into the underlying deposits (The Old Statistical Account of Scotland, 1791, Parish of Lecropt). The latter were the glacial marine beds of Jamieson, described by Milne-Home as bluish in colour and somewhat sandy in composition. James Geikie, writing in his account of "The Great Ice Age" (1894), considered these beds with their accompanying peat cover to represent the landscape that had existed prior to the deposition of the carse-clay.

This was virtually the sum-total of information available on the sub-carse deposits at the beginning of the present century. In the fifty years that followed, very little of direct relevance was added. However, changes were taking place in basic ideas of glacial advance and retreat and these have a greater bearing on the present investigation than is perhaps apparent at first sight.

Prior to 1914, many stratigraphical records were made available, especially east of Stirling, as mining companies sank numerous bores in search of coal. Some of these were used by H. M. Cadell in 1880 to examine the drift sequence in the Bo'ness area, and most of the information obtained was incorporated in his major work, "The Story of the Forth", in 1913. Although he did consider the superficial deposits, Cadell appears to have been more interested in the broader aspects of the geology and geomorphology of the Forth valley, spending considerable time, for example, in plotting the "pre-glacial" courses of the various rivers of the area. Finding evidence of drift lying on rockhead at some two and three hundred feet below sea-level, he inferred a great deal of river erosion while the sea lay well below its present level. Later bores showed even greater thicknesses of drift -- down to a maximum of 675 feet (205 m) below sea-level -- and present opinion, following that of Macgregor (1940) and Soons (1960), sees such deep buried troughs as being due to glacial over-deepening. Although the time of formation of these deep rock-basins has not been established absolutely, it is known that ice passed through this area several times and it is probable that the great depths were produced by the combined effects of more than one glaciation.

Relatively little is known about the earlier ice movements, but from the information available for the more recent period it has been deduced that a sequence of considerable complexity developed following the maximum of the last glaciation (Fig.I.3). As long ago as 1863 A. Geikie showed that a period of valley glaciation followed the decay of the last ice-sheet in Scotland. However, this was seen mainly as a temporary interruption in the fairly regular decay of the "mer de glace" and it was 1926 before the idea of ice-sheet readvance was introduced. In that year, Charlesworth described a major movement of Highland ice out over the Central Lowlands meeting ice covering the western and central Southern Uplands. An ice-limit was described as extending from St. Abb's Head, along the northern slope of the Lammermuirs, through the Tweed Basin and across the Solway lowlands to Stranraer. This limit and the features associated with it was referred to as the Lammermuir-Stranraer moraine. Later examination cast doubt on the inclusion of the central and eastern parts in the system while the northern section was linked with a readvance in the Aberdeen area to become the Aberdeen-Lammermuir Readvance (Sissons, 1961, 1965). Despite this, Charlesworth's paper was significant in that it introduced the readvance concept.

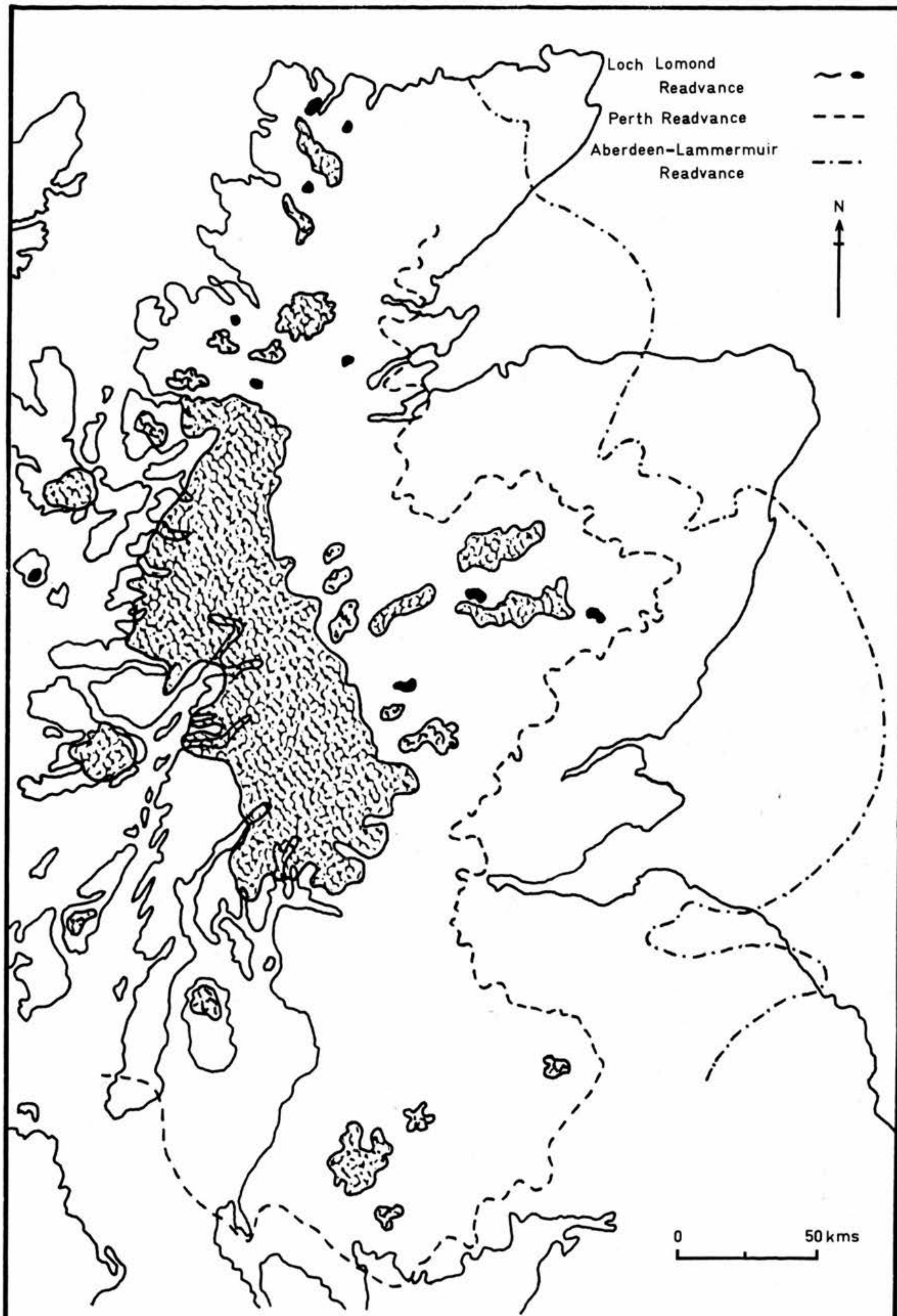


Figure 1.3 Successive limits of the last ice-sheet in Scotland

(After Sissons, 1967a.)

Following the postulated Aberdeen-Lammermuir Readvance, widespread deglaciation took place. It seems certain that glaciers did not disappear completely from the land and after a relatively short time they readvanced again. In this second case the ice was much less extensive, ice-streams from the Highlands, for example, reaching only limited areas of the Central Lowlands. The readvance was first demonstrated, in 1933, by J. B. Simpson in an area close to Perth in the Tay valley. Predictably it was called the Perth Readvance.

Evidence for this resurgence of the ice was provided by a section exposed a few miles northwest of Perth in the valley of the Almond, one of the tributaries of the Tay. Here, a layer of till, 12 feet (3.7 m) of which was exposed, was covered by a succession of 40 feet (12.2 m) of laminated clays and 15 feet (4.6 m) of sand and gravel. The finer sediments were considered to have been deposited following the retreat of the ice that had laid down the till and, from the measurement of some of the varves in these laminated clays, Simpson estimated that they had accumulated over a period of 640 years before the ice reasserted itself and produced the sands and gravels at the top of the section. Although they did not show the presence of ice at the site itself, these sands and gravels, being part of an extensive sheet of outwash leading down-valley towards Perth, recorded the return of ice to the vicinity and therefore completed evidence for a readvance.

Simpson found no such precise evidence for the readvance in the Forth valley, but from the distribution of morainic deposits and meltwater channels, he considered that ice had advanced in this area also. He saw the Forth and Teith glaciers coming together west of Stirling, the latter being diverted north-eastwards along Strath Allan to merge with the ice in Strath Earn, while the former passed through the Stirling gap and spread out eastwards. The exact position of the ice-front at this time could not be determined, but it was suggested that Glenfarg, a gap in the Ochils south of Perth, acted as a meltwater channel from south to north at this time. As a result, the ice was thought to have reached as far east as this. However, after consideration of sea-level changes, Sissons (1962) pointed out that the ice-margin was more likely to have extended only as far as the Stirling area and soon after Smith (1965) placed the limit of the Perth Readvance close to the present location of Kincardine-on-Forth.

While this ice was moving down the Forth and Tay valleys, similar glaciers were advancing down the glens of the Eastern Grampians and even larger ice streams were moving over Ayrshire and the Clyde Basin. Ice from the latter area passed around the southern edge of the Campsie Fells and into the valley of the River Carron, reaching the area where Larbert now stands (Simpson, 1933; Sissons, 1963). During the decay of this ice, meltwater carried great quantities of sand and gravel into the Carron and the Forth itself. For the most part, however, the activity of the ice in these other areas is of limited relevance here and as such requires only this brief mention.

With the decay of the ice, great volumes of outwash material were carried away from the receding ice-front and, in places, were built into the sea. Where this happened, outwash plains can sometimes be traced into raised beaches as continuous features. Subsequent isostatic uplift has caused these beaches to be raised well above sea-level and, in certain localities in both the Firths of Forth and Tay, they form rather conspicuous features, the most obvious of these having been termed the Main Perth Raised Beach (Sissons and Smith, 1965a). This beach would appear to have been formed when the ice was at its maximum extent or shortly after this, for it has been found to merge into outwash near Kincardine, Plean and Larbert, the limits of the readvance. Followed eastwards the Main Perth Shoreline declines at a rate of about 2.25 feet per mile (0.43 m/km) Fig.I.2 , from slightly below 125 feet O.D. (38.1 m O.D.) at Plean to 77-78 feet O.D. (23.5-23.8 m O.D.) at the Forth Road Bridge and 67 feet O.D. (20.4 m O.D.) at Burntisland (Sissons, Smith and Cullingford, 1966).

As the ice-margin retreated westwards, the meltwater streams continued to build up outwash plains and pour fluvioglacial debris into the sea. However, with variations in the relative rates of eustatic rise of sea-level and the isostatic recovery of the land, deposition did not take place at the same height as the Main Perth Beach. Since the level of the land in relation to the sea was rising these later beaches were formed at lower levels, as can be seen near Falkirk where two raised beaches at 84-88 and 108-109 feet O.D. (25.6-26.8 and 32.9-33.2 m O.D.) have been differentiated on the raised delta of the River Carron, while the Main Perth Beach stands at 116-119 feet O.D. (35.4-36.3 m O.D.). Followed westwards towards Stirling, the middle member of this series has been found to rise with a gradient similar to that of the Main Beach, reaching a height of almost 125 feet O.D. (38.1 m O.D.) before merging with outwash laid down when ice paused or even readvanced in the Stirling gap. Proof for such an assertion has been found in shoreline height differences east and west of the town. Immediately east of Stirling, the maximum altitude of the middle shoreline has been measured at 125 feet O.D. (38.1 m O.D.), but to the west the highest shoreline is only 73-76 feet O.D. (22.3-23.2 m O.D.) suggesting that ice stood in the gap long enough to witness a relative lowering of sea-level of 50 feet (15.2 m) (Sissons, Smith and Cullingford, 1966).

As well as the raised beach mentioned at 73-76 feet O.D. (22.3-23.2 m O.D.) to the west of Stirling, other fragments lie between 65-70 feet O.D. (19.8-21.3 m O.D.). For the most part, these are poorly developed or of limited extent and as a result correlation is difficult. Sissons (1967) has pointed out, however, that they are definitely absent from within the Menteith Moraine and therefore cannot have been formed after the moraine was built up.

When Simpson (1933) considered the movement of the Perth Readvance ice in the Forth valley, he admitted that a precise location for the ice-front could not be given. However, from general observations it seemed certain that the Forth glacier had extended beyond Stirling. In addition he drew attention to the presence of a well-marked moraine several miles to the west in the upper reaches of the Forth valley, indicating a further halt subsequent to the Perth Readvance. On investigation, it was found that the moraine not only pointed to a standstill, but also an advance of the ice-front. By consideration of glacially diverted rivers, it was possible to show contemporaneity between this moraine and a similar feature curving around the southern end of Loch Lomond. Both features were very distinct and sharply delimited, suggesting the possibility of a readvance and proof of this was supplied by the presence of shells in the moraines. Simpson named this second resurgence of ice, the Loch Lomond Readvance.

Although Simpson considered only the upper Forth valley and the Loch Lomond area, numerous writers have drawn attention to the existence of clearly defined, hummocky, morainic topography in many parts of the Highlands and Southern Uplands (J. Geikie, 1894; Wright, 1937; Charlesworth, 1955). The distribution of this hummocky moraine shows that the ice seldom spread out beyond the mountains at this time, pointing to the relatively small scale of the readvance compared with its predecessors. Despite this, evidence for the presence of the Loch Lomond Readvance is often more impressive than that of the earlier readvances.

Such is the case in the Forth valley, where, at its maximum, the Perth Readvance produced no morphological feature comparable to the very obvious Menteith Moraine of the Loch Lomond Readvance. Simpson (1933) followed the moraine for some 12 miles (19.2 km) from a point west of Buchlyvie in Stirlingshire in an arcuate loop across the Forth valley in the direction of Aberfoyle. From Buchlyvie as far as Arnprior the moraine comprises a series of mounds and ridges of sand and gravel, descending from a height of 800 feet O.D. (243.8 m O.D.) to almost 200 feet O.D. (60.9 m O.D.) at Arnprior, where the complex turns abruptly northwards. At this point, the moraine contains transported, shelly, marine clay. North of Arnprior, the system is broken by the River Forth, but beyond this it forms a conspicuous series of ridges, especially where it fronts the Lake of Menteith, reaching a height of about 100 feet O.D. (30.5 m O.D.). Here again, shelly marine clay is mixed with the more common sand and gravel. Near Port of Menteith, the morainic system turns sharply westwards, rising somewhat before dying out along the steep hill slopes (Simpson, 1933; Sissons, 1967a).

At its maximum the ice in the Forth valley pushed out into a sea that stood at 65 feet O.D. (19.8 m O.D.), according to Simpson. This value was inferred from the presence of marine clay at that height beneath the moraine, but it is now known that the clay is ice-transported, not *in situ*, and as a result Simpson's figure is no longer valid. However, an examination of the fluvioglacial deposits associated with the readvance has allowed another estimation to be made. Measurements on the surface of the outwash in the vicinity of the Goodie Water, the stream draining the Lake of Menteith, have shown a gradual altitudinal decline from 77 feet O.D. (23.5 m O.D.) down to 33 feet O.D. (10.1 m O.D.) where the gradient increases somewhat sharply. It was considered that this break at 33 feet (10.1 m), following the gradual decline from 77 feet (23.5 m), indicated the sea-level to which the outwash deposition was related. Similar measurements on outwash near Arnprior have indicated a possible sea-level at 37-38 feet O.D. (11.3-11.6 m O.D.). Both outwash plains must have been formed when the ice stood at the moraine, since the configuration of any ground exposed by a retreat would have disrupted the supply of meltwater and prevented their growth (Sissons, Cullingford and Smith, 1965; Sissons, 1966). Thus it would appear that at the time of the Loch Lomond Readvance the sea-level stood close to 35 feet O.D. (10.7 m O.D.).

Unfortunately, any evidence of features associated with such a sea-level has been hidden by later deposition. Indeed, the outwash plains referred to above were in part buried beneath carse-clay and peat, necessitating a considerable amount of boring before they could be located and measured. Perhaps due to difficulties of observation and perhaps due to a certain lack of interest, the interpretation of the buried deposits of the Forth valley proceeded only slowly. The work of Jamieson (1865), Milne-Home (1871) and Cadell (1913) has already been introduced and this provided the only information of any importance for a considerable length of time. It was only relatively recently, in the 1950's and particularly the 1960's, that this work was expanded to any extent.

In 1954, Parthasarathy investigated the superficial deposits of the Devon valley, part of the Forth basin, finding an essentially similar stratigraphy to that recorded by Jamieson farther west. In addition, he considered the texture, salinity and mineral content of the carse, concluding that it was of marine origin. At the same time a lower deposit, separated from the carse by a buried peat or gravel layer, was also interpreted as having been deposited in a marine environment.

He therefore recorded the following as a representative stratigraphy for the area:

5. Recent alluvium.
4. Carse clays.
3. Sands and gravels (or peat in places).

2. Lateglacial marine clays.

1. Boulder clays.

Although the findings were not completely unexpected, the methods with their emphasis on analysis and measurement were undoubtedly an improvement on much that had gone before.

At the other end of the carse, on Flanders Moss, a different approach was tried when Durno brought pollen analysis to bear on the deposits. He compared the stratigraphy at two sites, one at Blairdrummond similar to that examined by Jamieson, and one on Flanders Moss a few miles to the west. Deposition of the carse clay beneath the peat at Blairdrummond was considered to belong to the Atlantic climatic period, according to work carried out by Erdtman (1928). However, when Durno came to examine sediments lying below the thick peat of the Moss, he found heavy, bluish, silty clay which pollen analysis showed to be at least of Boreal age (Durno, 1956, 1958), and therefore having no correlation with the Atlantic period carse-clay of Blairdrummond. Since the latter was not represented in the Flanders Moss profile, the conclusion drawn was that the limit of the carse-sea transgression lay somewhere between the two sections examined (Fig.I.4). This was despite the fact that it had long been recognised that the carselands extended to the Menteith Moraine and beyond.

It was left to Sissons and Smith (1965b), to resolve the anomaly. Using boreholes put down by the Scottish Peat Survey and by themselves, they showed the existence of two roughly circular areas, in the western part of the Carse of Stirling, where carse-clay was absent and thick peat occurred instead (Fig.I.5). The

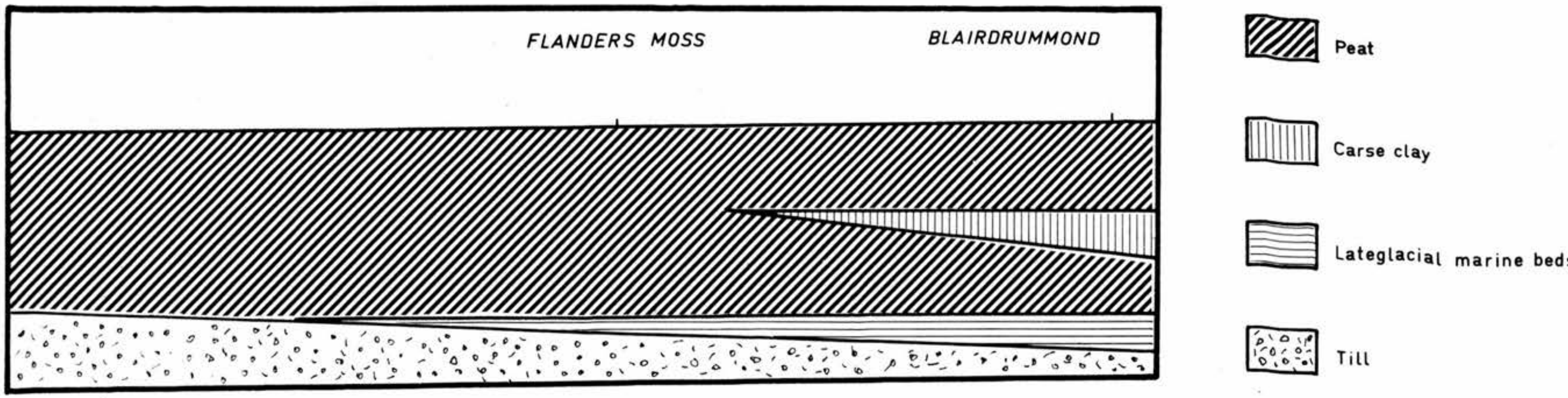


Figure 1.4 Superficial deposits in the Flanders Moss area, according to Durno (1958.)

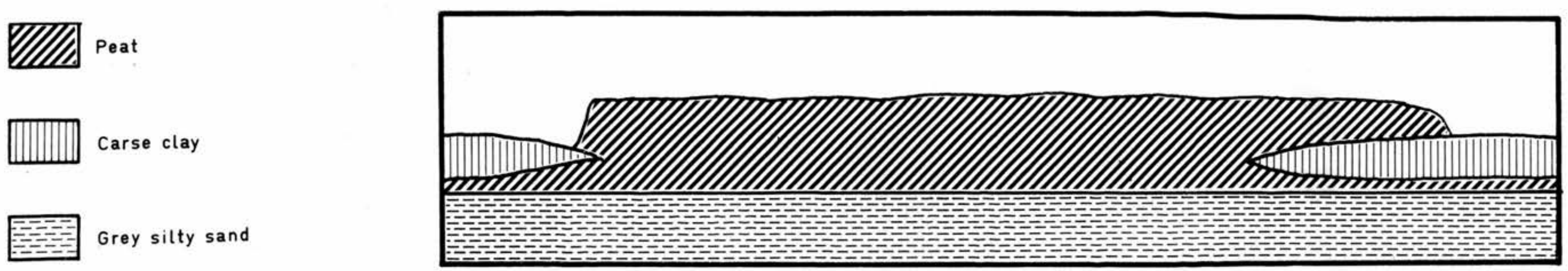


Figure 1.5 Superficial deposits in the Flanders Moss area, according to Sissons (1967a.)

latter lay on Lateglacial marine beds that were regarded as the sediments of a raised beach. Since this beach was completely obscured by later sediments, the term "buried raised beach" was coined. As the sea responsible for the beach retreated, it exposed an area, eminently suitable by reason of its subdued nature and poor drainage, for the growth of peat, which came to blanket almost the whole surface. When in turn the carse-sea transgression occurred, the largest part of the peat became buried beneath the associated carse-clay. However, in the two areas mentioned above, in East and West Flanders Moss, the peat, lying as it did at the head of the estuary and probably helped by isostatic recovery, was able to maintain itself above sea-level. In time, the carse-sea fell back and the mosses grew over the surface of the clay, obscuring the evidence for some 5000 years.

Although the above paper was mainly concerned with clarifying the situation with regard to the missing carse-clay, it also drew attention to the presence of a raised beach beneath the clay and peat. This was the first time such a name had been applied to the Lateglacial marine deposits.

Further work in the area (Sissons, 1966), brought to light the fact that the sub-carse peat lay at several different levels on surfaces that were flat or gently inclined and considered to represent beaches formed during periods of high sea-level in Late-glacial and Postglacial times. Three different beaches were identified, lying between 20 and 40 feet O.D. (6.1 and 12.2 m O.D.). Distinguished mainly by altitude, but also by the nature of their sediments, they were referred to as the Low, Main and High Buried

Beaches (Fig.I.6).

The High Beach was found only outside the Menteith Moraine and on the south side of the Forth where its shoreline was at an altitude of about 40 feet O.D. (12.2 m O.D.). In composition it was mainly pink silty sand with a thin cover of peat. The beach varied in width from 200-600 yards (180-550 m) and, followed away from the shoreline, it declined to about 36 feet O.D. (10.9 m O.D.) at its outermost edge. Here a slight bluff of a few feet separated it from the Main Beach, which was measured at 31-34 feet O.D. (9.4-10.4 m O.D.) along its shoreline and 28-31 feet O.D. (8.5-9.4 m O.D.) along its margin. This buried beach covered a large area both inside and outside the Menteith Moraine, its greatest extent being immediately east of the moraine on the north side of the river where it measured 1.5 miles (2.4 km) in a north-south direction and at least 2.5 miles (4.0 km) in a west-east direction. As in the case of the High Beach, peat covered this middle surface, but with thicknesses of at least a foot and often more, while the beach itself was composed mainly of fine, silty sand of light grey colour. Similar deposits formed the Low Beach except in the upper few feet which were sticky grey clay with stems of reeds extending downwards from the overlying peat. This lowest feature was found both inside and outside the moraine, at heights varying from 25.5-28 feet O.D. (7.8-8.5 m O.D.) in the first case and 21-25 (6.4-7.6) in the second. North of the Forth it was found to be higher, standing between 25.5 and 27 feet O.D. (7.8 and 8.2 m O.D.). Followed towards the Forth from both sides the Low Beach died out, usually quite sharply, and in a belt varying in width between 0.25 and 0.75

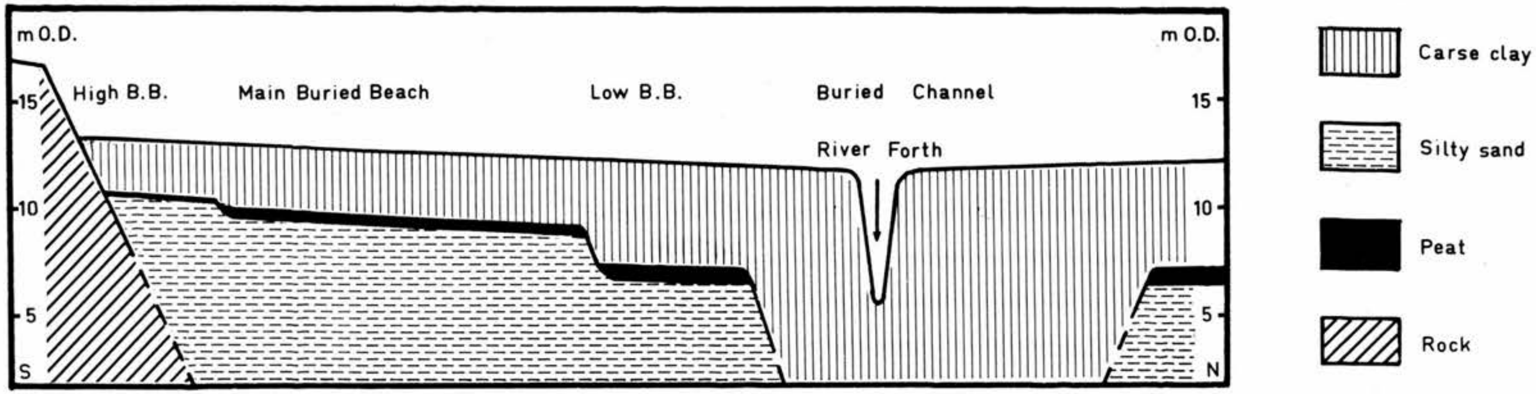


Figure 1.6 Buried beaches in the western part of the Carse of Stirling (After Sissons, 1967a.)

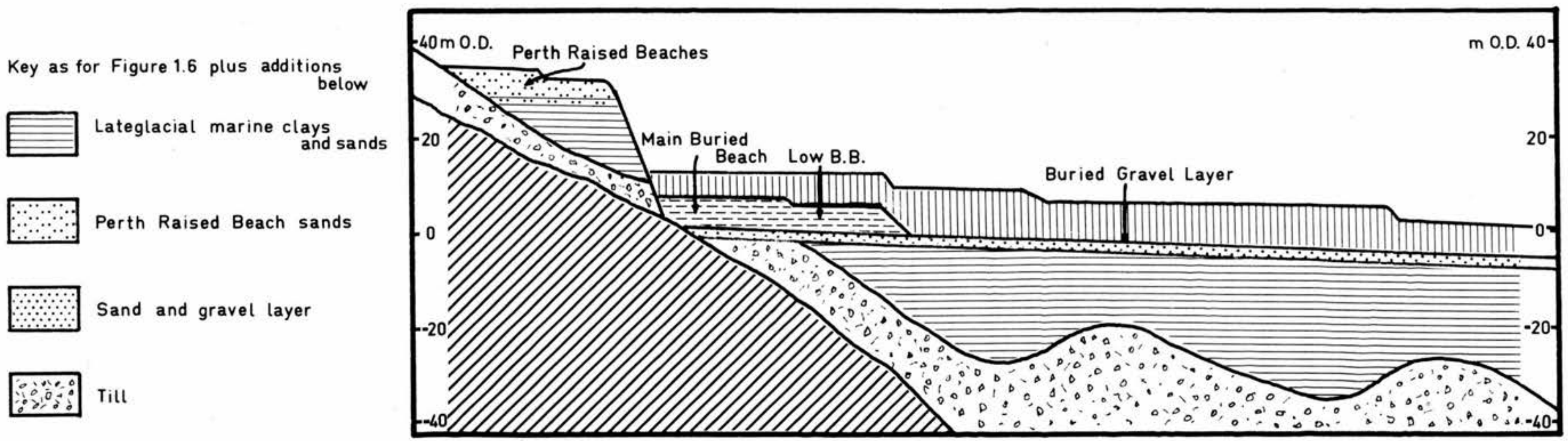


Figure 1.7 Superficial deposits in the Grangemouth – Airth region (After Sissons *et al.* 1966.)

miles (0.4 and 1.2 km) -- apparently following the trend of the present meander zone of the river -- no beaches were encountered and carse-clay alternated with layers of sand and sandy clay in which marine shells were found. It was suggested that this central belt was at one time an estuary in which sandy river deposits mixed with estuarine muds (Sissons, 1966; 1967a).

As well as being gently inclined towards the buried valley of the Forth, the Main and Low Buried Beaches were shown to have shorelines sloping gently eastwards as a result of isostatic tilting at a rate of 0.8 feet per mile (0.15 m/km) for the Main one (Fig.I.2) and a little less in the case of the Low. Both were traced down-valley, past Stirling to Bannockburn (Sissons, 1967a). The High Buried Beach on the other hand, was found only in a very limited area in the vicinity of the Menteith Moraine.

That portion of the carse to the east of Stirling, on the south side of the Forth and in particular, the area around Grangemouth, also proved conducive to further study. Numerous commercial boreholes, put down during site investigation prior to industrial development in the vicinity of the town, were supplemented by shallow hand-borings until an accurate picture of the stratigraphy of the area was built up (Sissons, 1969). The Main and Low Buried Beaches were again located, but perhaps the most significant element in the present context was an extensive layer of gravel. It varied in thickness from a few inches to 5.0 feet (1.5 m) rising gently from about minus 20.0 feet (6.1 m) to approximately Ordnance Datum and then rising more rapidly to as much as 20.0 feet (6.1 m) above sea-level in places. Its composition of rounded stones and sand intermixed with marine shells, suggested a further buried beach but it bore no similarity to those already referred to, for the latter were composed mainly of fine sediments. Sissons saw the buried gravel layer as indicating a period of marine erosion, his supposition being supported by the presence of marine cliff forms at the outer edge of the Perth Raised Beach deposits and the existence of planated rock and till surfaces beneath the carse-clay. Erosion of rock, till and the Lateglacial marine deposits (the last containing much ice-rafted debris), appeared to have provided material for the beach now represented by the buried gravel layer.

Important as the gravel layer was in its own right, showing a hitherto unrecognised period of extensive marine erosion, its position with respect to the other deposits proved rather significant. Traced landwards from the Forth it was found to pass beneath the sediments of the other two buried beaches in the area, thus indicating relative ages (Fig.I.7). Older then than the Low and Main Buried Beaches, it could be shown to be younger than the Perth Raised Beaches, since the associated cliff truncates the latter. Thus, in terms of relative age, the buried gravel layer could be located with considerable certainty.

This raises the whole question of dating, so far only touched upon in a very general way. Indeed, general relative dating was really all that was available to the early workers. It is only recently that the techniques of pollen analysis and radio-carbon dating have allowed present-day investigators to become much more specific than their predecessors.

With regard to the present investigation, most of the stratigraphical elements mentioned above have been supplied with absolute dates, or have been related to known dates. In considering these it is probably best to start with the youngest units, which are also perhaps the most obvious, and work backwards.

The presence of peat in the Forth valley helped dating considerably. Pollen analysis from Ochtertyre Moss showed that the peat, overlying the carse-clay here, began to accumulate during the late Atlantic climatic period (Erdtman, 1928). Radio-carbon measurement at a later date from nearby Flanders Moss gave a figure of 5,492 ± 130 B.P., for the base of the peat (Godwin and Willis, 1962). Despite a slight discrepancy, these results were generally taken as confirming each other and since they refer to the base of the peat, must also give a date by which the carse-clay had ceased to accumulate. Using similar techniques, it proved possible to investigate the buried peat to obtain the time at which the carse-sea transgression began. At Airth, between Stirling and Grangemouth, the top of the buried peat was carbon dated at 8,421 ± 157 B.P. (Godwin and Willis, 1961). Comparing the two dates, a period of some 3,000 years is obtained during which carse-clay was deposited.

More recently this relatively simple explanation has been revised somewhat and it is now recognised that the carse-clays form four Postglacial shorelines (Smith, 1965; Sissons, 1967a). Smith (1968) used this fact to explain the slight age difference between the peat at the base of Flanders Moss and that at the base of Ochtertyre Moss. In the former case the peat was considered to lie on the Main Postglacial Raised Beach, while in the latter it lay on a lower and slightly younger beach. With two additional beaches at lower levels, it seems likely that the carse-clay accumulated for more than 3,000 years and a date of approximately 4,000 B.P. has been estimated for the third beach in the series (Sissons, 1967a). In addition, localities in the southwest of Scotland have produced radio-carbon dates that show the formation of the Main Postglacial Beach there, to have been earlier than in the Forth valley. At Lochar Moss and Newton Stewart, dates of 6645 ± 120 B.P. and 6159 ± 120 B.P. respectively, have been obtained from deposits overlying the stratigraphical equivalents of the carse-clay showing the earlier retreat of the transgression from its maximum, in this area (Godwin and Willis, 1962).

Using such techniques, care must be taken in the choice of horizon from which samples are taken, especially if dates of sea-level change are to be inferred from the results. Although dates obtained from buried peats in Scotland are relatively numerous, the fact that they have been collected without too much attention to this, means that they are less useful than they might have been. Partly as a result of this and partly because the buried peat is not all of the same age, in any case, carbon dates from the buried peats cover a fairly wide range.

The oldest of these buried peats was measured in the Solway Firth, at Redkirk Point, between Annan and Carlisle, where a bed of peat gave an age of 12,290 ± 250 years (Godwin and Switsur, 1966). At the same site, a peat bed slightly above this one and approximately at present sea-level, was estimated at about 10,300 years old. In the west and southwest generally, the peat appears to be older than in the east. In the former, dates of 9,620 ± 150 B.P.

at Irvine, 9,362 ± 150 B.P. at Girvan and 9,640 ± 180 B.P. at Brighouse Bay, in Kirkcudbrightshire, can be quoted. One exception to this trend is a date of 8,135 ±150 B.P. at Redkirk Point in Dumfriesshire (Godwin and Willis, 1960-62). In contrast, the dates for localities further east tend to be later. For example, in the Earn Valley at Eastfield of Dunbarney and Broombarns, dates of 8,421 ± 157 B.P. and 8,354 ± 143 B.P. respectively have been obtained. The figure of 8,421 ± 157 B.P. for Airth can also be noted here (Godwin and Willis, 1961). Exotic results, such as the Geological Survey's dates of 3,249 ± 160 B.P. for the peat/carse boundary in the Forth valley and 3,656 ± 150 B.P. for sub-carse gravel in the Teith valley indicate further that although radiocarbon dating is a great advance on other techniques, it may present new problems of interpretation.

Returning to the more particular problems of the Forth, the dating of the buried beaches can be approached from a consideration of the peat that intervenes between them and the carse-clay. Before the idea of buried raised beaches had been formulated, it had been shown by pollen analysis that the glacial marine beds in the Flanders Moss area were of Boreal age (Durno, 1956). The location of these sediments placed them in what was later called the Main Buried Beach and from the analysis it was inferred that the age of the feature was around 9,500 years (Sissons and Smith, 1965b). Using similar methods, but with a greater knowledge of the sub-carse deposits, this date was confirmed by pollen analysis of peat at another point on the beach (Newey, 1966). Working through the uppermost sediments of the beach itself and into the lower few centimetres of the peat, Newey noted the presence of *Chenopodiaceae* and *Gramineae* pollen, which he considered to indicate salt-marsh conditions. This showed not only the marine origin of the buried beach but also pointed to the fact that the peat had begun to grow while the sea was still vacating the beach. Thus, when the base of the peat lying upon the Main Buried Beach was shown to belong to the transition between Zones IV and V of the pollen sequence, corresponding to an age of about 9,500 years, this figure could be taken as the approximate age of the beach itself.

In the same way, Newey proved the marine origin of the Low Buried Beach and showed it to have been formed wholly during Zone V. In this case the date was verified by the radio-carbon method which gave a figure of 8,690 ± 140 B.P. for the peat immediately above the beach. The result did not agree with dates from comparable situations in England and Northern Ireland, being slightly younger (Godwin and Willis, 1965). It was thought possible that there might be a lack of exact synchronisation between pollen zones in the Forth valley and the areas mentioned. However, in the peat above the Low Beach there were numerous tree-trunks and branches and it seemed that these trees, growing at a later date than the basal peat, might have sent roots down into it, thus slightly reducing its apparent age. Bearing in mind also that the peat had to be slightly younger than the surface on which it grew it was suggested that the Low Buried Beach ceased to be formed about 8,800 years ago (Sissons, 1966).

While carrying out pollen analysis of the peat overlying the Low Beach, Newey (1966) had noted marine influences in the lower layers indicated by the presence of *Gramineae* and *Chenopodiaceae* pollen. Followed upwards these types of pollen were replaced by the normal freshwater swamp and arboreal pollen, such as *Sphagnum*, *Salix* and *Betula*. Near the top of the peat layer salt-marsh pollen was again found, pointing to the return of marine conditions. The succession showed the lowering of sea-level after the formation of the Low Beach, when the sea became restricted to the buried estuary, and its eventual return to produce the carse-sea transgression. By obtaining dates from the base of the peat and from the top, it was possible to estimate the length of the period during which the buried estuary was occupied. As already noted, the Low Beach was vacated about 8,800 years ago. Radio-carbon measurement of a sample taken where the peat began to merge with the overlying carse clay, gave a date of 8,270 ± 160 B.P., by which time the rise in sea-level, that produced the carse, must have been in progress. Taking the two dates together, the sea occupied the buried estuary for approximately 500 years and it was suggested that a minimal sea-level during this time was reached about 8,500 years ago (Sissons, 1966).

Such techniques of pollen and carbon-dating could not be used in the case of the High Buried Beach, due to the paucity of peat on its surface. However, by reference to a previously dated feature, the Menteith Moraine, an approximate figure was obtained. Unlike the other buried beaches, the High Beach was not encountered within the moraine, which suggested that it accumulated while ice was still present. On the other hand, the sediments of the beach were discovered lying immediately above outwash gravels near Arnprior, showing that the High Beach was formed after the outwash deposits were laid down. The evidence therefore restricted the formation of the beach to a period after the construction of the moraine and associated outwash, but before the retreat of the ice from the moraine.

By comparison of pollen zones present outside and inside the limits of the Loch Lomond Readvance, Donner (1957) had placed the formation of the moraines in Zone III of the pollen sequence. Confirmation of this was obtained from radio-carbon dates of shells in the Loch Lomond and Menteith Moraines which gave figures of 11,700 years and 11,800 years respectively. In the case of the Forth, this implied that the sea extended to the head of the low-lands during Zone II, its deposits being redistributed by the Menteith glacier and incorporated in the moraine during the Zone III cold phase. With this additional evidence, the Zone III readvance was confirmed, giving a date for the formation of the moraine in the vicinity of 10,300 B.P. Bearing in mind the stratigraphical relationship between the moraine and the High Buried Beach, it was suggested that the latter was produced at, or shortly after this time (Sissons, 1967a).

The dating of the buried gravel layer was approached in a similar fashion. As already indicated, the stratigraphy showed it to have been formed sometime after the Perth Readvance Raised Beaches but prior to the Buried Beaches, which gave limiting dates of 13,500-13,000 B.P. -- the present provisional date for the culmination of the Perth Readvance -- and 10,300 B.P. -- the date of formation of the High Buried Beach (Sissons, 1967a). Such a period of 3,000 years is very different from the more precise dates for the formation of other features, but with the relatively limited evidence available at present greater precision is not possible.

In conclusion, it should be pointed out that of all these features, only the Menteith Moraine and the carselands form elements of the landscape in the area covered by the present study. Comparing the dates of formation of the two, it can be seen that some 5,000 years lie between the time when ice stood at Menteith and the time when the carse-sea began to fall back from its maximal limit. Evidence of the geomorphological activity of these years now lies beneath the carse, but in the course of the following chapters it is hoped that the carse-clay can be metaphorically removed to expose the landscape beneath.

CHAPTER II

METHODS EMPLOYED IN THE PRESENT STUDY

Many, if not most, of the early stratigraphical records of sub-carse deposits in the area adjacent to the River Forth were obtained from chance exposures observed when streams were low or when deep drainage ditches were dug at the time of the moss-clearances. With the advent of commercial boring, knowledge of the stratigraphy was increased greatly in certain areas, but the overall coverage remained very limited, restricting any interpretation that might be attempted. To remedy this, a comprehensive boring programme was begun by J. B. Sissons in the western part of the Carse of Stirling, the methods used being described in the Institute of British Geographers' special publication on shoreline displacement (1966). The present survey follows similar lines, but, in addition, introduces laboratory analysis of the sub-carse deposits. With this in mind, the methods can be described in terms of those used in the field and those used in the laboratory.

Methods of Fieldwork.

Boring. The basic fieldwork was carried out using a hand-borer, modified from the Hiller-type peat borer by the addition of steel bands at the extension-rod joints. With this it was theoretically possible to reach a depth of 10 m from the surface, but in practice this was either seldom required or impossible to reach due to the tough nature of the deposits. The toughest part of the carse itself was usually the top metre which was removed with a normal soil auger before the Hiller borer was inserted. Within the area studied, this layer of tough clay -- the carse-crust -- varied in thickness, apparently as a function of drainage. In well drained arable land, near ditches and streams or in areas underlain by gravel, the crust increased in thickness to almost 2.5 m in places, making boring very difficult. On the other hand, where the carse was badly drained, near the remnants of the once extensive peat mosses, the crust was very thin and beneath the peat itself, usually non-existent.

Individual borehole depths varied considerably, from less than 1.0 m to a maximum in excess of 8.0 m depending upon several factors. The greatest depths were reached in bores which passed down into the buried valleys underlying the Forth and most of its tributary streams. In the Devon valley, a maximum of 8.9 m was reached while holes beside the Goodie Water and the Forth itself commonly produced depths in excess of 6.0 m, compared with the general average of 3.5-4.0 m. Deeper holes were also required where peat was present on top of the carse-clay. These reached figures of 7.5-8.5 m on Flanders Moss, the upper stratum being entirely peat 3.5-4.5 m thick.

Since the deposits lying beneath the carse-clays were being investigated, the thickness of these clays and the depths of particular boreholes showed a marked relationship, strengthened by the fact that, in most cases, the sub-carse deposits proved too tough for penetration with the equipment available.

In the first phase of fieldwork, lines of boreholes were put down at varying intervals across the carse, in a north-south direction, in an attempt to establish a general stratigraphical pattern. The spacing of the boreholes varied from as little as 5 m to as much as 200 m, although 50 m intervals were most common, giving reasonable accuracy as well as ease of measurement both on the ground and on paper. The smaller intervals were necessary for accurate delimitation in areas of rapid horizontal change in the sub-carse deposits and were required in the location of the shorelines of what proved to be buried marine features.

With the completion of twelve such traverses, the basic distribution had begun to emerge. To supplement this pattern, a further series of borings was made with two main aims; firstly, to provide links between adjacent traverses at the same time filling in the broader picture and secondly, to allow some statistical examination of the buried landforms, for which careful selection of borehole location was necessary. For example, in the second case, short lines of closely spaced bores in certain areas enabled buried shorelines to be recognised. With accurate heighting, these could be related to former sea-levels and any warping since formation could be measured. Again, where the bores were relatively numerous, and after heighting, it was possible to draw formlines to give a reasonable representation of the surface shape of the deposits.

The borehole logs obtained from this programme are listed in Appendix A.

Levelling. As already mentioned, the results of boring were used to show the position and height of former shorelines. It has been established that for this information to have any real meaning accurate heighting is a primary requirement. Different methods are available, depending very much on individual intepretations of the word "accurate", but, for the purposes of this study it was decided to measure all heights by levelling. Two facts prompted this. In the work already done on the sub-carse deposits of the Flanders Moss area all heights were the result of levelling. Continuity and comparison, therefore, demanded similar methods in this present work. Furthermore, with the Hiller borer it was possible to achieve an accuracy of 1-3 cm in the measurement of stratigraphical boundaries. To take proper advantage of this fact, any instrument or combination of instruments less accurate than a surveyor's level and staff could not be considered.

All levelling was carried out with reference to Ordnance Survey bench-marks or to temporary marks derived from these official heights, and all traverses were closed. From the figures produced, the closing error was calculated, the aim being to keep it as low as possible in relation to the length of traverse, although variation did occur within a range of 0.00 feet to 0.60 feet. Higher figures such as the latter were allowed in certain instances, for example, over the buried valley of the Forth, where slightly less accuracy could be tolerated, but in most cases the closing error did not exceed 0.10 feet. The original altitudes in feet derived from the levelling were converted to metres for ease of comparison with the metric calibration of the Hiller borer and to coincide with recent trends towards the adoption of the metric system in studies such as this.

In the area east of Stirling, it was found that certain bench-mark heights did not agree with the published figures due to extensive mining subsidence. This difficulty was overcome by using heights measured by D. E. Smith (1965) and corrected to the Fundamental Bench-Mark at Menstrie. A further check, made by comparing these heights one against the other, enabled obvious differences to be taken into account.

A few boreholes - less than a dozen - were not levelled, where the distribution of a particular deposit was considered more important than its height.

Refraction Seismography. As a possible supplement to boring, some consideration was given to the investigation of the sediments of the area by means of a portable refraction seismograph -- a Soiltest Terra Scout. At first sight this appeared to provide a simple and rapid method of sub-surface survey. However, there proved to be several inherent difficulties. The apparatus comprised the Terra Scout itself (basically an oscilloscope tube) a geophone and a tamper, the latter objects being connected through the receiver in such a way that shock waves generated by the tamper were picked up by the geophone, to be converted into a wave pattern on the receiver screen. From this, the time taken for the shock waves to travel from the tamper to the geophone was obtained by fixing an adjustable reference point on to a chosen position on the wave. When the two points had been made to coincide, the time required, in milliseconds, could be read from a graduated counter on the face of the receiver. By varying the distance between tamper and geophone from 2.0 m to 50.0 m, a series of times could be built up and plotted on a time/distance graph, which could be shown to contain a number of facets. The exact number depended upon the various strata through which the shock waves had passed. In turn, the gradient of each facet could be measured and by reference to a nomograph the rate of passage of the shock waves through each stratum could be calculated. Similarly, the depths at which changes in the stratigraphy occurred could be obtained. The final step was to identify the various strata, which was made possible by the ability of different rock types to allow the passage of shock waves at different rates. By simple comparison with prepared tables the elements of the stratigraphy could then be identified.

Although reasonably simple in operation, the refraction seismograph had certain drawbacks as far as the present investigation was concerned. In the first place, it required two persons for its use compared with the one necessary for hand boring. Such a difficulty was by no means insurmountable, but in several other respects the seismograph compared badly with the borer. One of the primary principles of seismic work is that density of the deposits being investigated increases with depth. As it happens, in the area of the carselands such a requirement cannot always be met due to the presence of buried peat. Seismic survey could still be carried out, but the peat, being overlain by denser carse-clay would not be recorded - an omission of considerable proportions when it is noted that this sub-carse peat can be as much as 1.5 m thick. Apart from this, the stratigraphy as a whole could not be so accurately represented by the seismograph. Depending upon sub-surface conditions errors of up to 0.3 m could be expected compared with the few centimetres possible with the Hiller borer. Furthermore, when identifying the deposits from their velocity figures a certain amount of overlap occurred. For example, the following are typical values for some rock-types to be found in the area under study.

Sandy Clay	1,200-1,900 ft/sec.
Gravel	1,600-2,600 ft/sec.
Glacial Till	1,800-7,000 ft/sec.
Sandstone	3,000-9,000 ft/sec.
Shale	2,600-11,000 ft/sec.

In such a situation, it would be necessary to put down check boreholes which would virtually double the time taken at any one site.

Perhaps the main asset of the refraction seismograph was depth of penetration which could be 3 or 4 times greater than that possible with the Hiller. However, taking the factors already mentioned into account, it would appear unwise to place too much emphasis on seismic survey without borehole control. Where boring was relatively easy, as in the case in question, it was doubtful if seismic work added substantially to the information obtained by the former method. Thus, following some initial work for comparison with boring, no additional seismic surveying was carried out.

Commercial Boreholes. As a further source of information, the logs from a large number of commercial boreholes, ranging from well-sinkings to site investigation probes, were acquired. These proved to be of mixed usefulness. In a study where accurate heighting was important, the complete absence of heights in many cases was somewhat disconcerting. In addition, there were reports carrying no locational details. At the other extreme were holes, numbering no more than fifty, which in location, height and detail compared very favourably with those bored with the Hiller. All in all it was apparent that the bulk of the commercial bores had to be used with extreme care and where possible in conjunction with accurate hand boreholes.

These, then, were the methods used in the field. They were related to laboratory work through the collection of sediment samples which were analysed by the methods indicated below.

Laboratory Methods.

Before any laboratory analysis could be carried out, samples had to be collected and prepared. This in itself gave rise to several problems, not the least of which was the determination of points from which samples were to be obtained. It was not possible to use a purely objective pattern of sampling (e.g. every third borehole) since the nature of the buried landscape was not apparent until a certain amount of boring had been done. Dependence on such a scheme would have involved continual duplication of effort. Ideally, the problem could have been solved by sampling from every stratum in every hole, but the drawbacks in terms of time and volume of material were obvious.

After the completion of several traverses, it had become increasingly apparent that major differences did exist in the sub-carse deposits with regard to colour and texture, but at the same time, within these units, large areas of remarkably uniform sediments were also present. It was therefore decided that a relatively flexible pattern would be adopted, based on samples taken wherever deposits in adjacent holes showed change in colour or composition. To supplement these, further samples were taken at random with the aim of examining the uniformity within particular sedimentary units. Thus, the sampling system is almost entirely empirical, chosen for the information it might provide on the similarities and differences already partially recognisable by visual inspection.

Apart from the initial problem of deciding upon the distribution of samples, there were further difficulties, mainly of a mechanical nature. Firstly, the sub-carse deposits often proved too tough for penetration to the full extent of the Hiller sample chamber, making it difficult to collect a reasonable size of sample. Any attempt to increase this by a second extraction from the same hole was virtually useless, for as soon as the borer was removed for the first time, liquid carse-clay and peat flowed to the base of the hole to contaminate any subsequent sample. This difficulty also meant that results from many of the samples referred only to the top 20-30 cm of the deposits.

Secondly, where the underlying deposit was gravel, no sampling was usually possible unless the constituents were very small. However, with experience, some indication of the nature of the gravel could be obtained from the effect it had on the Hiller. Big gravel, for example, locked the borer fast, whereas smaller gravel allowed a certain amount of movement but little penetration, and gravel mixed with sand permitted the occasional sample.

Added to the samples from the sub-carse deposits were a number from the carse itself, collected for purposes of comparison.

Almost 100 samples were obtained and all were air-dried on porous plates before being ground and sieved. Sieving in the first instance was through a 2 mm mesh and it was noted that, in most cases, the whole sample could be passed through the sieve, giving an indication of the fine nature of the deposits with which the investigation was concerned. The dried, sieved sediments which resulted from this preparation were stored in labelled glass jars.

Analysis for pH. Simply defined, the value quoted for the pH of a soil sample is the measure of the hydrogen ion concentration in that particular sample. The basic theory behind this is in part rather complicated but experience has shown that a simple scale derived from this is adequate for most purposes. On the scale, the value 7 stands for neutrality, higher figures indicating alkalinity and lower acidity, with an unbroken range of possibilities in between.

All samples collected in the present study were measured for pH using a Cambridge Direct-reading Meter, calibrated for buffer solutions of pH 4 and pH 7. Comparison of the unknown samples with these solutions of known value gave the required results and the use of two buffers allowed a check to be kept on the figures obtained. Additional cross-reference was attempted by variation of the fluid suspensions from which the readings were taken. All samples were measured in distilled water initially. However, under normal conditions, the water contained in sediments is not pure, but contains salts in solution. It was therefore decided to take further readings from samples in a solution of calcium chloride, the salt most commonly used to simulate the natural situation. In the final analysis, these were the results used and the figures obtained with distilled water were kept merely as a check.

Analysis for organic carbon. One of the more obvious differences between the carse-clay and its underlying deposits concerns the organic content of each. It has long been known that the carse-clay contains abundant vegetable matter as well as numerous shell beds. In contrast, both are apparently lacking in the sub-carse deposits except in the uppermost parts where there is mixing with the overlying peat. Although obvious by inspection alone, an attempt at quantification was made. This proved unsuccessful for several reasons. In the first place, although the organic content of the carse-clays is high over the carse as a whole, it is mostly arranged in thin beds or lenses. As a result, small samples, such as those common in this investigation, could, and did, give widely differing results. A second source of error lay in the sampling of the sub-carse deposits. As indicated, in the majority of boreholes it was only possible to sample the top 20-30 cm. Where this was so the figures obtained for organic carbon content could not be considered representative, for at that depth in the deposit contamination by roots, stems and other vegetable matter from the overlying peat, was often considerable. In the sediments obtained from sections or the occasional deeper bore, the organic carbon percentages were very low, but these samples were not sufficiently numerous to allow definite conclusions to be drawn.

<u>Particle-size analysis</u>. With the completion of several borehole traverses, it became increasingly obvious that the sub-carse deposits were falling into broad patterns judged in terms of mechanical composition. Seemingly significant differences occurred, often quite sharply, between adjacent sites, but, as already noted, over large areas the uniformity of the sediments was quite remarkable. To examine these two aspects and to give them some quantitative basis, particle-size analysis of the various samples was carried out.

There were several methods of analysis available, ranging from sedimentation balances with automatic recording equipment or the pipette method with its fine adjustment to the simple routine hydrometer methods and more crude sieving techniques. After consideration of the equipment required and the balance to be struck between accuracy and ease of working, it was decided to use the hydrometer method.

Hydrometer analysis was carried out on that fraction of the sample which passed through a 2 mm mesh sieve. A known weight of the material was first treated with hydrogen peroxide to remove any organic matter that might give rise to flocullation and consequent false results in the sedimentation analysis. The sediments were then dispersed in a dilute aqueous solution of a deflocullating agent and allowed to settle. As settling took place, hydrometer measurements were recorded at varied but calculated intervals and the rate at which sedimentation took place was determined by the rate of decrease in density of the upper part of the liquid as the particles settled out.

The method depends on the fact that particles of different sizes have different settling velocities. With the aid of a nomograph based on this fact, the velocities of the particles were measured and their equivalent diameter computed on the assumption that they were spherical in shape. The results obtained for each sample were plotted on a semi-logarithmic graph, cumulative percentage against equivalent particle size diameter, from which the proportion of material in the various size fractions was obtained and reported in tabular form.

One drawback encountered in this method was the paucity of information received for the fine sand fraction, resulting in a poorer curve and less accurate estimation of the percentage of sediment in this sector. To improve on this, a slight variation was introduced involving sieving of the fine sand fraction. After wet sieving of a prepared sample through a 0.064 mm mesh, the material retained was dried and placed in a sieve nest with meshes of 2 mm, 1 mm, 0.5 mm, 0.25 mm and 0.125 mm. The nest was shaken for 15 minutes on an automatic shaker and the weight of material retained on each sieve finally recorded. In conjunction with this, the sediments which had passed through the original 0.064 mm mesh were subjected to normal hydrometer analysis.

From this second method it was possible to plot an increased number of points on the graph and in consequence a more accurate curve was produced.

All samples were analysed for particle-size composition. A number of checks were made in the usual way by running duplicate experiments with the same sample and the two methods used were compared in a similar fashion. As with other results the figures from particle-size analysis will be discussed where relevant in the following chapters.

Heavy mineral analysis. A natural consequence of particle-size analysis was the separation of the fine sand from the other fractions. This is most suitable for heavy mineral analysis since the fine sand has the broadest and most representative range of minerals. By a combination of flotation in bromoform, centrifuging and filtering, the heavy minerals (Specific Gravity 2.90) were separated from the light and slides of the former were prepared. These slides were examined under a polarising microscope, individual minerals being identified by resort to reference books and by comparison with specimen slides. In each case over 100 grains were counted and the results recorded as a percentage of the total.

Although the samples examined for heavy mineral composition were only a small proportion of the total, an attempt was made to choose those which appeared most representative. The numbers involved are probably too small for definite interpretations to be made from those results alone, but when viewed in conjunction with other factors such as field observations and mechanical analysis they throw a certain amount of light on the geological derivation of the sub-carse deposits.

The pages that follow contain the interpretations put upon the results obtained from the methods described above. Some are less important, others, such as the borehole logs, are obviously fundamental, but used together and in conjunction with careful observation in the field, they make it possible to describe and explain the landscape which lies beneath the carselands of the northern side of the River Forth.

CHAPTER III

THE STRATIGRAPHY AND SUB-CARSE MORPHOLOGY OF THE AREA BETWEEN THE MENTEITH MORAINE AND BLAIRDRUMMOND

The area with which this study is concerned is remarkably homogeneous. Apart from the Menteith Moraine, rising above the western carselands and the odd eminences protruding through the clay in the vicinity of the Stirling gap, it consists essentially of a long relatively narrow subdued plain, its regular surface broken by deep ditches, the remnants of the once extensive peat mosses and, beyond Stirling, by the scattered spoil-tips of coal mines. Along the southern margin flows the River Forth, its course incised in the clay, separating this northern portion of the carse from a similar area on the opposite side of the valley. Two major rivers, the Teith and the Devon, and two streams, the Goodie Water and the Allan Water, joining the Forth on its left bank, add a certain variety to the region, but all in all it is characterised by a considerable degree of monotony.

This is especially true from a morphological viewpoint and for descriptive purposes the carselands can be considered as a single unit. However, the present investigation is chiefly concerned with the deposits lying beneath the carse. When these are considered it can be shown that the area is divisible into three parts, two of which are essentially similar, but separated from each other by a unit which is geomorphologically very different from either. Taking points on the carse surface beneath which these units lie, they can be listed as follows:- the area between the Menteith Moraine and Blairdrummond, that between Blairdrummond and the Stirling gap and finally the remainder stretching from the Stirling gap to Kincardine-on-Forth and including the Devon valley. In the following pages these will be considered in turn, firstly in terms of their stratigraphy and secondly with reference to their morphology as it must have appeared prior to the deposition of the carse-clay.

The Menteith Moraine to Blairdrummond*

As already indicated in a previous chapter, the Menteith Moraine comprises a complex series of mounds formed largely of fluvio-glacial debris and glacially transported marine clays. Associated with the moraine are sheets of outwash that slope eastwards to pass beneath the carse-clay and related deposits. North of the Forth, the main mass of fluvioglacial gravel spreads out from a gap cut in the moraine by meltwaters and presently utilised by the Goodie Water. In this area, the course of the Goodie is an artificial cut and for a distance of almost 400 m the gravel can be followed eastwards as an exposure in the banks of the stream. Eventually, the gradual decline of the surface of the outwash carries it beneath the bed of the stream and further investigation is only possible after boring through the overlying deposits (Fig.III.2).

Some 400-500 m south of the Goodie Water, the carse shoreline trends roughly east-west and here the relationship between the out-wash gravel and adjacent deposits is again apparent. Deep drainage

*Figure III.1 is applicable to this entire section.

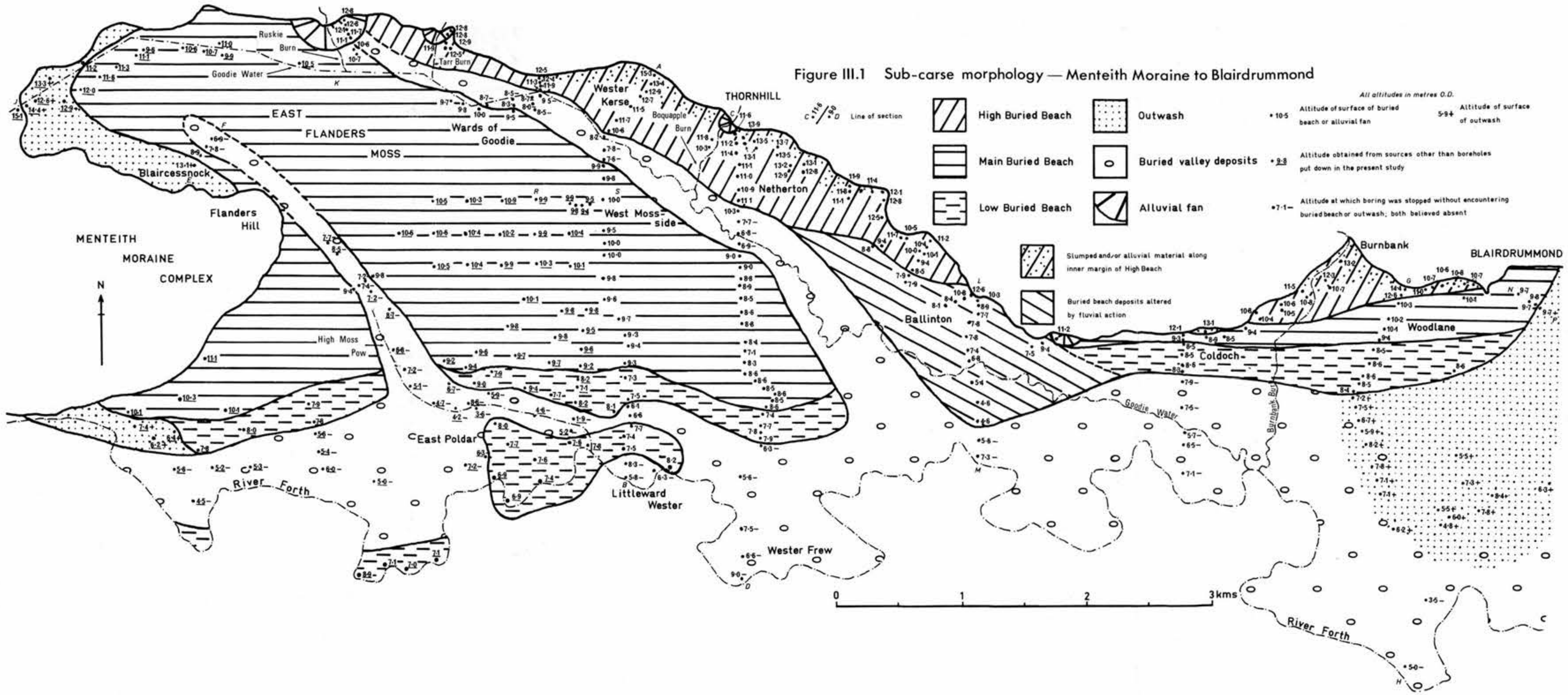


Figure III.1 Sub-carse morphology — Menteith Moraine to Blairdrummond ditches, cut to permit the afforestation of this area, have produced numerous exposures and from the slopes below Blaircessnock Farm, the gravel can be followed beneath the peat of Flanders Moss, which extends beyond the limits of the carse at this point. At about 100 m from the edge of the moss, the gravel passes below the carse-clay (Fig.III.3) and near the same point its surface falls below the base of the main ditches. Beyond this the presence of gravel was demonstrated by hand boring for some 200 m in a north-easterly direction before it disappeared or lay at depths which could not be reached with the equipment available.

The ditches in this area provide numerous exposures that show the gravel to be quite typical of outwash. The deposits are roughly stratified, consisting mainly of medium to large gravel but with coarse sand and finer gravel in places. The change from one size to the other is often quite sharp both vertically and horizontally, indicating rapid changes in channel position during the formation of the outwash plain. The well-rounded nature of individual stones is also representative of this mode of formation.

The greater proportion of the rocks that make up the outwash are Highland in origin, carried out of the hills behind Aberfoyle by the ice that produced the Menteith Moraine. Palaeozoic sedimentaries of Old Red Sandstone age form the bedrock of the area adjacent to the moraine, but the boundary with the Highland metamorphic rocks lies only a few kilometres to the west. Although no precise count was taken, the limited number of Old Red Sandstone fragments in the gravel was apparent in this particular area. The presence of a layer of marine clays immediately above the Old Red sediments appears to have been sufficient to limit the erosion of the latter, thus limiting its inclusion in this part of the moraine and consequently in the outwash. Towards the hills that back the carse, a higher proportion of Old Red Sandstone sediments in the gravel might be explained by deposition from streams flowing off these hills.

Quartzites, grits and schists are probably the most common rock-types present, corresponding to the petrology of the Highland Border in the vicinity of Ben Lomond and Ben Venue. The latter, according to Geological Survey maps, is composed of schistose grit, but also has a band of epidote-chlorite-schist associated with it. Green chlorite-schist is common in the outwash gravel and it seems probable that it originated in the neighbourhood of Ben Venue. This is the only rock type which can be related to a specific source by simple inspection. Detailed geological examination could undoubtedly improve on this, but for present purposes this is not necessary. The chlorite-schist is mentioned here, because it is distinctive, acting as an indicator, and in addition has further implications when certain of the sub-carse deposits are examined.

Measurements on the outwash, recorded by Sissons (1966) in the vicinity of the Goodie Water, show that it slopes from 23.5 m, at its western end, down to 10.1 m some 3 km farther east (Fig.III.2). Over this distance there is a gradual decrease in gradient until the surface is at a height of 10.1 m, where a sharp increase takes place. South of the Goodie, the same eastward slope is observable, but over a much shorter distance (Fig.III.3). Below Flanders Hill the gravel passes beneath the surface peat at a height of 14.9 m O.D. and slopes in a direction between east and north-east. The slope is rather great and at distances beyond 200 m from the edge of the moss the gravel cannot be located. Borehole 666 shows the outwash lying at 13.1 m O.D. while at a point 100 m to the east it is encountered at 8.2 m. Beyond this, boreholes were put down to 7.8 m O.D. and 6.9 m O.D. but the gravel could not be located. The gradient of the outwash surface in this second case is obviously much greater than in the first and requires some explanation. However, this is best done after consideration of certain other elements of the morphology of the area as a whole.

It has been pointed out above that eastwards from the moraine the outwash passes beneath surface peat and carse-clay. In fact, these are only the upper elements of a more complicated stratigraphy. Beneath the carse lies a bed of buried peat resting on the grey silty sand of a buried raised beach. The sloping gravel eventually passes beneath these also, so that immediately east of the moraine, the following elements can be taken as representative of the stratigraphy:

5. Surface peat.
4. Carse-clay.
3. Buried peat.
2. Grey silty sand.
1. Gravel.

The grey silty sand of this section corresponds to one of three buried steps recognised in this area by Sissons (1966) and distinguished by altitude as well as characteristic colour and composition of their constituents. Despite the differences, there are certain similarities that suggest a common origin. All are composed of fine water laid sediments with a remarkable uniformity of composition over large areas. All are relatively flat or gently inclined and occupy a position that at the time of formation would have been at or near the head of an estuary. Taken together, these facts suggest a marine origin, which has been proved by pollen analysis (Newey, 1966) for the two lower steps. It appears unlikely that the highest step had a completely different origin and all three have been called "buried raised beaches", due to their position beneath the carse but above present sea-level. (As already noted, the term "buried raised beach" will be used for deposits of both marine and estuarine origin lying beneath the carse, no distinction being drawn between the two.)

The three buried raised beaches discovered by Sissons on the south side of the Forth in this area seem to be present on the north side, occupying essentially similar positions with respect to each other but with certain significant differences. For convenience at this stage the buried beaches in the northern area have been provisionally equated with the southern features and will be referred to by Sissons' terms. This point is fully discussed and justified below (Chapter VII).

The highest buried beach is found in the northwestern part of the area under investigation. It forms a continuous feature extending for almost 5 km in an east-west direction with a width varying between 150 m and 750 m. At its inner or northern margin, where it ends against the steeply rising ground that also marks the inner edge of carselands, its height varies between 12.9-12.5 m O.D. in the west and 11.7-10.4 m O.D. at its eastern end. In general, there is also a slight slope outwards from the back of the beach, where the average height is 11.9 m compared with 9.5 m at the front. At Netherton Farm near Thornhill, however, the figures for back and front are 11.6 and 11.1 m respectively. For the most part, the surface of the beach is remarkably uniform except towards the backslope where the normal smooth profile is broken by hummocky deposits of coarse sand which appear to have slipped from the backslope while the beach was forming or after it had formed (Figs.III.4 and III.5).

The buried beach is covered by a layer of peat, varying in thickness from a few centimetres to half a metre at a maximum. East of Thornhill the peat is usually absent and the carse rests immediately upon the beach itself. The sediments of the beach are for the most part pink or purple-pink, except in the topmost 5-10 cm where there is a characteristic greyish coloration that exists irrespective of the presence or absence of overlying peat. Along the northern margin, the colour is often more brown than pink.

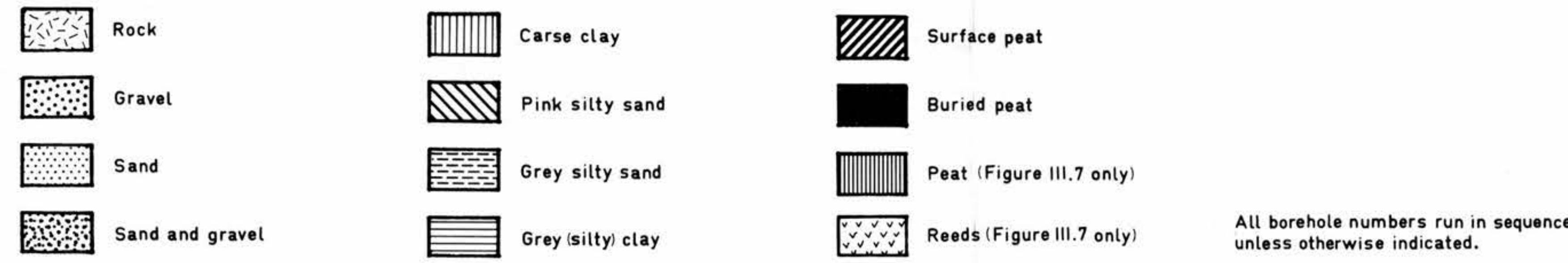
The variation in colour is parallelled to a certain extent by a variation in composition. There is little difference between the grey and pink sediments which are essentially fine grained with varying proportions of sand, silt and clay. However, the brownish-pink sediments are of a coarser texture, perhaps due to their proximity to the former shoreline. Coarser sediments are also associated with the burns that flow on to the carse from the higher land to the north. The Boquhapple, Tarr and Ruskie Burns appear to have been in existence and depositing sand and gravel into the sea at the time of formation of the pink beach, for in the vicinity of these streams, the beach sediments are usually coarser than in other areas. The logs for boreholes 634, 636 and 638 indicate this.

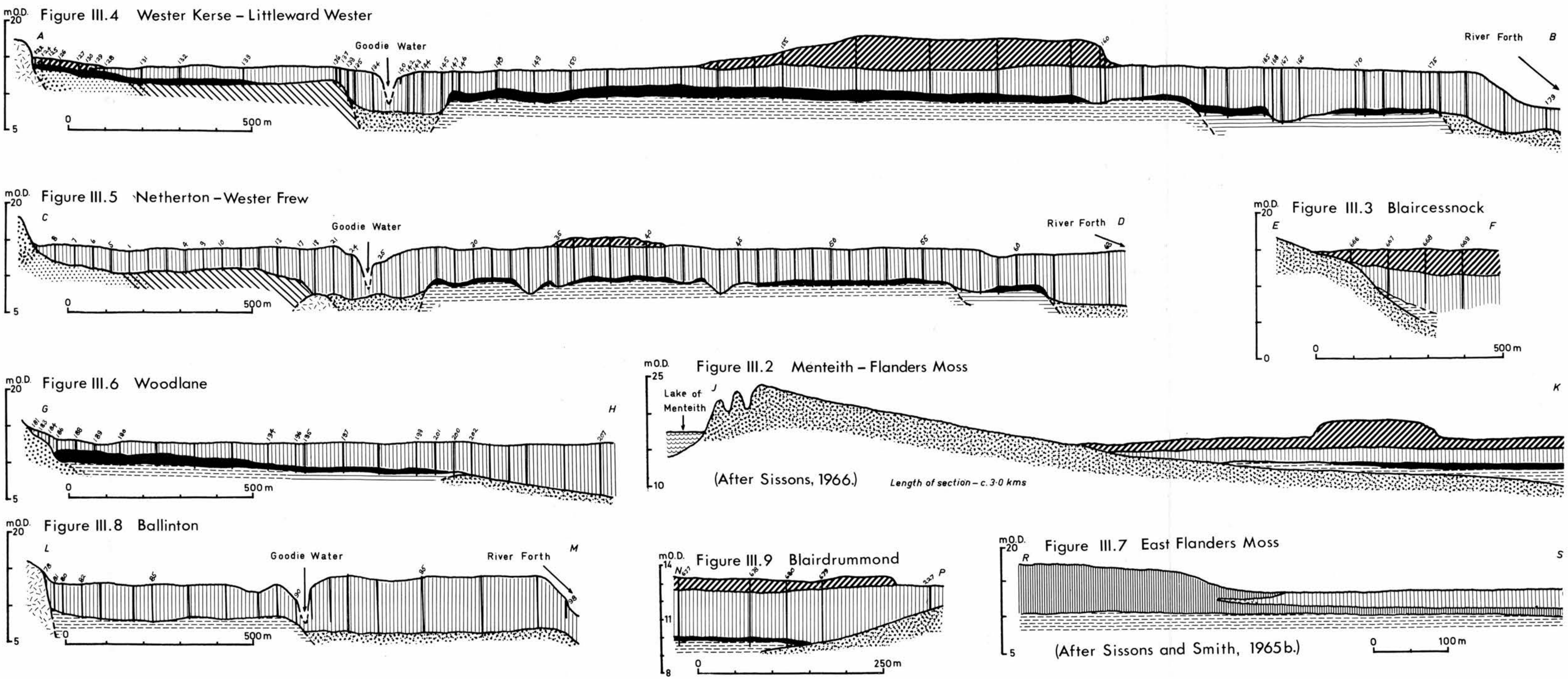
The Ruskie Burn has produced an alluvial fan which is now

THE SUPERFICIAL DEPOSITS OF THE AREA BETWEEN –

— THE MENTEITH MORAINE AND BLAIRDRUMMOND

(The location of each section is indicated in Figure III.1.)





buried beneath the carse. It can be followed for at least 300 m from the back of the carse and is composed of grey-brown fine sand for the most part with some clay in places. At first sight this bears little relationship to the pink deposits of the highest beach, but the latter appears to be represented by the presence of pink silty sand mixed with the fine grey-brown sand of the fan. One borehole (657) shows pink clay lying between the carse-clay and the grey-brown sand of the fan, at a height of 12.9 m O.D. This is the most westerly point at which the presence of the High Buried Beach has been indicated. Beyond the Ruskie fan, the boreholes are rather limited in number and position, but no evidence of the pink beach has been found there. If it is present, it can only be of very limited extent.

Traced southwards, the High Buried Raised Beach ends abruptly along most of its length. It is delimited sharply by a valley, also buried by the carse and more or less following the present course of the Goodie Water. The only exception to this occurs at the eastern end of the beach where, over a distance of less than a kilometre it lies adjacent to a subdued area of fine grey sand, the junction being marked by a slight rise half a metre high.

The buried valley can be traced for a distance of over 5 km in a south-easterly direction from a point near Wards of Goodie. It is only one of a number of valleys that lie beneath the carse in this area and they are best considered as a group. They will be described in some detail below, but at present an examination of the sediments lying to the south of the valley is more pertinent.

These sediments are a distinct element in the stratigraphy over a large part of the area under study. They consist essentially of grey silty sand with remarkable overall uniformity and belong to the Main Buried Raised Beach as designated by Sissons (1966). As noted above, the deposit is encountered immediately east of the Menteith Moraine overlying fluvioglacial gravel. From here, it can be traced for 11.0 km eastwards as far as Blairdrummond, with only one break where it is cut by a buried valley. Its maximum extent in a north-south direction is about 2.0 km.

The grey silty sand forms a surface that is almost flat, with only a gentle slope to the east. Near the moraine it is encountered at heights between 12.0 m and 11.1 m O.D. Although the exact position of the shoreline of the beach is not apparent, due to the presence of the buried valley along its northern edge, there is a slight slope to the south, representing the normal beach slope (Figs.III.4, III.5 and III.6). Heights of 10.1, 9.9 and 9.4 m O.D. along the back or northern margin correspond to figures of 9.2, 8.7 and 8.2 at the front of the feature.

The beach is composed almost entirely of fine grey or grey-green sand with considerable proportions of silt and clay. It also contains an abundance of micaceous fragments which impart a characteristic sheen to the sediments. It is thought that the green coloration and the mica may have originated in the breakdown of rock such as the chlorite-schist already remarked on as occurring in the Menteith outwash. The fine sand and silt fractions normally form the greater part of any sample and the term "silty sand" can be used to describe the deposit (Sissons and Smith, 1965b). In places, the upper few centimetres of the deposit have a high percentage of clay and here the term "silty clay" has been used. Such a situation is especially common between Coldoch and Blairdrummond, although by no means confined to that area.

The thickness of these deposits is not accurately known since the equipment used would not penetrate more than 50-100 cm into them and no commercial borehole records are available. In some cases this amount of penetration was sufficient to reach the underlying deposits (Boreholes 200 and 201 or 4/DES and 6/DES) but undoubtedly the thicknesses recorded are not representative, due to the thinning of the beach deposits in the vicinity of the Blairdrummond and Menteith gravels. The greatest thickness is recorded in borehole 653, put down in the bed of the Goodie Water, where 2.0 m of grey silty sand overlie coarse grey and pink sand. Complete penetration was also possible in a stretch along the back of the carse between East Coldoch and Burnbank. The grey silty sand varies in thickness between 9 cm and 34 cm and rests upon pink silty sand in a number of boreholes. (693, 695, 696 and 707.) Although the surface of the pink deposit varies in height between 10.8 and 8.3 m O.D., it may well represent the High Beach in this area, the height variations being produced by a combination of the Burnbank Burn and a small stream passing on to the carse near Coldoch House. This being so, the difference in height between the sea-level that produced the Main Beach and the surface of the High Beach must have been sufficient only for the deposition of a thin veneer of grey silty sand. Again this is a special case and with this limited amount of information, no accurate assessment of the general thickness of the Main Beach deposits can be made.

Almost everywhere the Main Buried Beach is covered by a layer of peat, sandwiched between it and the overlying carse. The peat varies in thickness from a few centimetres to over a metre, but commonly measures 10-20 cm. The greater thicknesses are found beneath East Flanders Moss and would appear to be associated with a gradual thinning of the carse. Near Thornhill, the average thickness of the carse above the Main Beach is 4.1 m while at West Moss-side, less than a kilometre to the west, it is only 2.9 m. Within a few hundred metres still farther west, the carse-clay is no longer encountered and the peat lying on the Main Buried Beach is continuous with the surface peat of Flanders Moss. This situation is found in a roughly circular area, noted by Sissons and Smith (1965b) and explained by them as indicating the position of a peat bog that was able to maintain itself within the encroaching carse-sea (Chapter 1). Here the peat has a depth in excess of 7.0 m, resting directly upon the grey silty sand of the Main Buried Beach. Technically this is the greatest thickness of peat above the deposits of the Main Beach, but it is obviously atypical and the figures already quoted are most common.

In many boreholes a transition zone is found to occur at both the upper and lower limits of the buried peat, showing the continuity of the progression from buried beach, to peat and eventually carse-clay. Five or ten centimetres of transitional deposits, consisting of peat mixed with clay or grey silty sand are not unusual but often the zone of mixing is too small to merit inclusion in the borehole logs.

Within the peat layer itself, woody material is often present. No distinct pattern is visible as far as vertical distribution is concerned. Sometimes the wood is found in the top of the peat layer, sometimes in the bottom, occasionally it replaces the buried peat completely and frequently no wood is present at all. In a horizontal direction, the wood appears to follow some pattern, for it is more common in some areas than in others, suggesting a patchy distribution of the original trees. There is also considerable variation in the type of wood encountered. The presence of smooth, slightly silvery bark can be used to recognise birch, the wood of which is soft and light yellow in colour. Fragments recovered in the borer also included pieces of soft red, and hard dark brown or black wood, which local inhabitants claimed to recognise as pine and oak respectively. Other, non-arboreal, vegetable matter is also recognisable in the buried peat in places, including stems of *Juncus* and *Phragmites*, as well as the shiny red seeds of *Menyanthes trifoliata*. Undoubtedly, the distribution of these fragments is of some significance, as Newey (1966) has shown, and would merit further investigation by botanists and palynologists, but in the present study, the limited number of samples taken within the peat layer and limited botanical knowledge meant that the variety of vegetable matter could be no more than noted.

In an area, 2.0 km south-east of Thornhill, the grey silty sand is not covered by peat (Fig.III.8). Here also the deposit is at a much lower level than is normal for the Main Beach in this area. North of the Goodie Water, heights range from 7.8 m O.D. to 7.3 m O.D., which are at least 1.0-2.0 m lower than might be expected from comparison with adjacent areas. Despite the similarities in colour and composition between the sediments of this area and those of the Main Buried Beach, the height difference raises problems. However, the variation may be associated with a change in position of the buried valley of the Goodie Water.

At its southern edge, the step that forms the Main Buried Beach descends through a height of 0.5 to 1.5 m below which the lowest buried beach is reached. This is the smallest of the three beaches first recognised by Sissons (1966) and is best developed west of the Goodie Water. It is widest in an isolated island beneath the carse in the vicinity of East Poldar Farm, where it attains a north-south width of almost 500 m (Fig.III.4). In most areas it exists as a narrow strip, no more than 150-200 m wide. West of the Goodie Water, it occupies a position on the southern margin of the Main Buried Beach and is continuous for a distance of nearly 5 km in an east-west direction, with only a short break in the vicinity of High Moss Pow.

Of the 35 heights obtained on the surface of this Low buried beach, only four lie outwith the range 8.2-7.3 m O.D. There is no apparent pattern to the distribution of the heights, although the lowest heights within the range given are found towards the eastern end. However, this may be related to the greater number of boreholes put down in that particular area. Again there is no slope towards the front of the beach as was found in the two previous cases, although on the isolated mass mentioned above, the heights tend to be greater along the northern margin than on the southern.

In colour and composition, the Low Beach is somewhat similar to the Main Beach. It is grey or greenish-grey in colour and consists of sticky silt and clay in the top 30 or more centimetres. Beyond this, the deposit becomes gradually more sandy by the inclusion of thin layers of fine grey sand until it resembles the sediments of the Main Buried Beach. On the latter, however, the cover of silty clay is not usually so thick nor is it so extensive. Like the Main Beach, this lowest feature contains a considerable proportion of fine micaeous particles.

The grey silty clay of the Low Beach usually contains numerous stems of reeds that merge upward into the overlying peat. This peat is as much as 40-50 cm thick and is often difficult to penetrate, due to its compressed nature, as well as the high proportion of wood it contains. Lying as it does, beneath more than 5.0 m of carse-clay in most cases, compression has been intense; so intense, in fact, that tree branches obtained from the peat layer, where it is exposed in the banks of the River Forth, can be oval in cross-section due to the pressure from above. As a result, the peat layer is very tough and in some cases penetration was impossible. Where this was so, the thickness of the peat and therefore the height of the Low Beach has been estimated from the average figures recorded in the surrounding area. This may involve some degree of error, but it seems unlikely to be more than 10-20 cm.

The deposits of the Low Buried Raised Beach and the peat associated with it are exposed in the banks of the Forth at a number of points, mainly in the western part of the area. In most places, however, approaching the Forth the Low Beach disappears, the carse becomes thicker and layers of sand alternate with the lower layers of the clay. Marine shells and shell fragments are also found in these lower layers. From work carried out in this area and on the south side of the Forth, it is apparent that there is a belt, varying in width from half a kilometre to a kilometre and following the general trend of the meander zone of the Forth, in which neither the buried peat nor the buried beach deposits are present. This belt is taken to indicate a buried valley that operated as an estuary at different times in the past.

As already indicated, there are a number of buried valleys beneath the carse in this area. That of the River Forth is the major one, but there are also valleys beneath the Goodie Water and High Moss Pow that can be thought of as tributary to the main buried valley. In addition, there are also buried valleys or gullies cut into the surface of the buried beaches. These are normally very limited in both depth and width but are quite numerous in places as can be seen in the Netherton-Wester Frew section (Fig.III.5). They are most commonly found in the Main Buried Beach, seldom more than a metre in depth and containing none of the buried peat that normally covers the surface of the beach. Samples from the bottoms of these valleys give sediments little different from the normal grey silty sand of the beach, suggesting that they are products of erosion rather than areas of non-deposition of beach sediments. The absence of peat within the gullies can be explained by the presence of flowing water when the peat blanket was growing.

These gullies appear to have acted as tidal creeks as the carse-sea rose, for shell beds may be found within them (e.g. Boreholes 42, 44 and 45). The shells are often very well preserved, both valves being intact in some cases, and it is relatively easy to identify different genera. *Cardium* is probably the most common shell encountered, but *Mytilus* and *Ostrea* are also found in considerable quantities.

In contrast to these relatively small gullies, the main buried valleys are rather impressive features. As already pointed out, the valley beneath the Goodie can be traced for a distance of over 5.0 km, while the High Moss Pow valley at about 3.0 km is slightly shorter. It is probable that the small valleys drained into these main ones, the latter in turn joining with the larger buried estuary of the Forth.

For most of its length, the buried valley of the Goodie Water follows the course of the present stream and its junction with the main buried valley lies close to the confluence of the present stream with the Forth. A few hundred metres west of Wards of Goodie, the two features -- stream course and buried valley -- diverge, the latter continuing in a north-westerly direction while the former trends roughly east-west. From that point westwards, peat and grey silty sand can be located in or beneath the bed of the stream whereas downstream neither is encountered. From that point also, the buried valley begins to peter out and a few hundred metres to the north-west it is replaced by the coarse grey-brown sand of the Ruskie fan. Water from the Ruskie Burn probably flowed into the pre-carse Goodie Water helping to produce and maintain the buried valley.

The heights obtained within the buried valley show a considerable range from section to section, being greatest in the north-west and least in the south-east near the junction with the valley of the Forth. Taking average figures, there is a reduction in height downvalley from 8.7 m O.D. at Wards of Goodie, through 7.7 m at Netherton Bridge, to 4.9 m O.D. at Bridge of Goodie. Because of the limited penetration possible with the Hiller borer in coarse sediments, these heights may not be representative of the valley floor. However, the heights quoted indicate points at which the deposits are increasingly difficult to penetrate and, bearing in mind the method of boring, the points should be related to each other. This is borne out by the coarse nature of the sediments in the valley. Thus, although the slope indicated need not refer to the valley floor, it does appear to be applicable to sediments lying upon this floor.

In several boreholes (18, 19, 20, 23, 645 and 648) it is possible that rockhead was reached. Due to the limitations of the equipment used and the absence of commercial boreholes, this could not be proved conclusively, but there is reason to believe that rock was encountered. In the boreholes mentioned the presence of a solid object was indicated by a dull "ring" transmitted up the shaft of the borer. This sometimes happens if the end of the borer hits an individual stone in a mass of gravel. However, in that case it is often possible to displace the stone and work the boring screw into the gravel, after which the instrument usually jams. With big gravel containing large cobbles this might not be possible, individual stones being too large to displace. In an attempt to discover whether or not this was so, three boreholes (18, 19 and 20) were put down, 5.0 m apart, in a triangular pattern. In each case, after the dull "ring" of the borer striking, no further penetration could be achieved and the maximum height difference on the rock or gravel surface was only 3.0 cm. It is possible that in each hole the borer came down against a large piece of gravel but this seems unlikely and when a similar situation was discovered only 10.0 m from borehole 20, it was considered probable that rockhead had been reached. Thus, the picture of the buried valley of the Goodie Water is of a valley 150.0-400.0 m wide with fairly steep sides, lying some 2.0-4.0 m below the level of the adjacent buried beaches, its floor covered by coarse sand and gravel through which solid rock occasionally protrudes, and sloping in a south-easterly direction towards the main valley of the Forth.

Much less is known about the buried valley that lies beneath High Moss Pow. This is due mainly to its relative inaccessibility, reaching as it does, well into East Flanders Moss. However, near its south-eastern end, the moss has been cleared from the carse surface and the buried valley can be located more easily there. It is represented at the surface by a shallow depression through which the Pow flows. Followed back on to the Moss the depression persists, becoming narrower upstream. The limited number of boreholes that have been put down through the surface peat indicate the absence of buried peat or buried beach deposits but establish the existence of coarse sand and gravel alternating with the carse-clay in its lower layers or lying beneath it (Boreholes 373/JBS-377/JBS). At the same time two lines, of four boreholes each, at right angles to the general trend of the valley show that the grey silty sand of the Main Beach lies to either side of it (Boreholes 630-633 and 666-669).

The buried valley of High Moss Pow is on a smaller scale than that of the Goodie Water, at least in terms of length, being almost 2.0 km shorter. It is at least 100.0 m wide one kilometre upstream from its junction with the Forth and appears to widen towards the main valley. Heights within the valley vary from more than 7.0 m O.D. near its head to 5.2 m O.D. near its mouth, with a variety of values at intermediate locations. The exact upstream limit of the valley has not been located, but it appears to fade out a few hundred metres north-west of Flanders Hill, where a continuous cover of grey silty sand is found. Thus, despite the limited amount of information available, a buried valley can be seen to exist beneath High Moss Pow and indeed the very existence of the present stream may well be due to the presence of that valley.

Both of the valleys described join up with the main buried valley of the River Forth which can be followed to Stirling and perhaps beyond. In the area west of Stirling, there are few commercial boreholes and the altitudinal information obtained normally refers to levels beyond which it is not possible to penetrate with the Hiller borer. Those boreholes that have been put down between Menteith and Blairdrummond show great thicknesses of superficial deposits: thus on the south side of the Forth, rockhead was ultimately reached at 99.4, 38.9 and 14.6 m below Ordnance Datum. Similarly, at Bridge of Frew, on the Forth, figures of -18.0, -4.1 and -3.3 m O.D. have been obtained. In contrast, using the Hiller, rockhead could not be located, the lowest altitude reached being 1.9 m O.D., where boring was stopped by gravel. The greatest proportion of heights lies between 5.0 and 7.0 m O.D., sufficiently far below the level of the buried beach deposits to preclude their presence but undoubtedly, in most cases, still far from rockhead.

Along its northern margin, the buried valley of the Forth is relatively sharply defined, the changeover from beach to valley taking place in a horizontal distance of as little as 10.0-25.0 m. Such definition is common in the western part of the area, but in the east the margin of the buried valley is not so sharp. In the vicinity of Blairdrummond, coarse sand and gravel carried out on to the lowland by the River Teith has been deposited in the buried valley of the Forth and it is difficult, if not impossible, to decide where the Teith sands and gravels end and those of the Forth begin. In places, shell fragments enable a distinction to be made (Boreholes 216 and 218) but these are the exception rather than the rule.

The morphological units first encountered immediately east of the Menteith Moraine are limited in their eastward extension by the sands and gravels associated with the River Teith (Fig.III.9). Not only do these deposits interfere with the buried valley of the Forth but they also limit the buried beaches in this area. The sediments of the Main Buried Raised Beach can be followed eastwards almost as far as Blairdrummond, where they overlie the alluvial fan of the Burnbank Burn and eventually die out against the rising sand and gravel of the Teith system (Boreholes 227, 677, 678, 679 and 680) in much the same way as they do in the west against the Menteith outwash. Thus, at Blairdrummond, a sharp morphological boundary occurs and this has been utilised for purposes of description.

Conclusion

The carselands on the north side of the River Forth between the Menteith Moraine and Blairdrummond mask a variety of morphological elements that can be summarised as follows:-

1. The Menteith outwash plain sloping from a height of 23.5 m O.D. near the moraine to pass beneath the carse-clay and its peat cover at about 15.0 m O.D. to reach a low of 10.1 m, 3.0 km farther east.

2. The High Buried Raised Beach, lying beneath the northern limits of the carse, at heights mostly between 10.0 and 12.0 m O.D. and composed of pink silty sand for the most part.

3. The Main Buried Raised Beach, the most extensive of the buried beaches, overlapping onto the outwash plain at a height of about 11.0 m O.D. and sloping gently eastwards to an average height of 9.0 m O.D. near its eastern end. The sediments of the beach are grey in colour and of the texture of silty sand. A bed of peat is normal on the surface of this feature.

4. The Low Buried Raised Beach, lying along the southern fringe of the Main Beach, west of the Goodie Water, at heights between 7.0 and 8.0 m O.D., the least extensive of the three beaches. Grey in colour, it varies in composition from silty clay at the surface to silty sand at depth. Like the Main Beach, it commonly has a peat cover.

5. The buried valley of the River Forth, along with those of its tributaries, the Goodie Water and the High Moss Pow, diversifying the sub-carse morphology and producing belts of mixed sediments that contrast sharply with the uniformity of the beach deposits.

CHAPTER IV

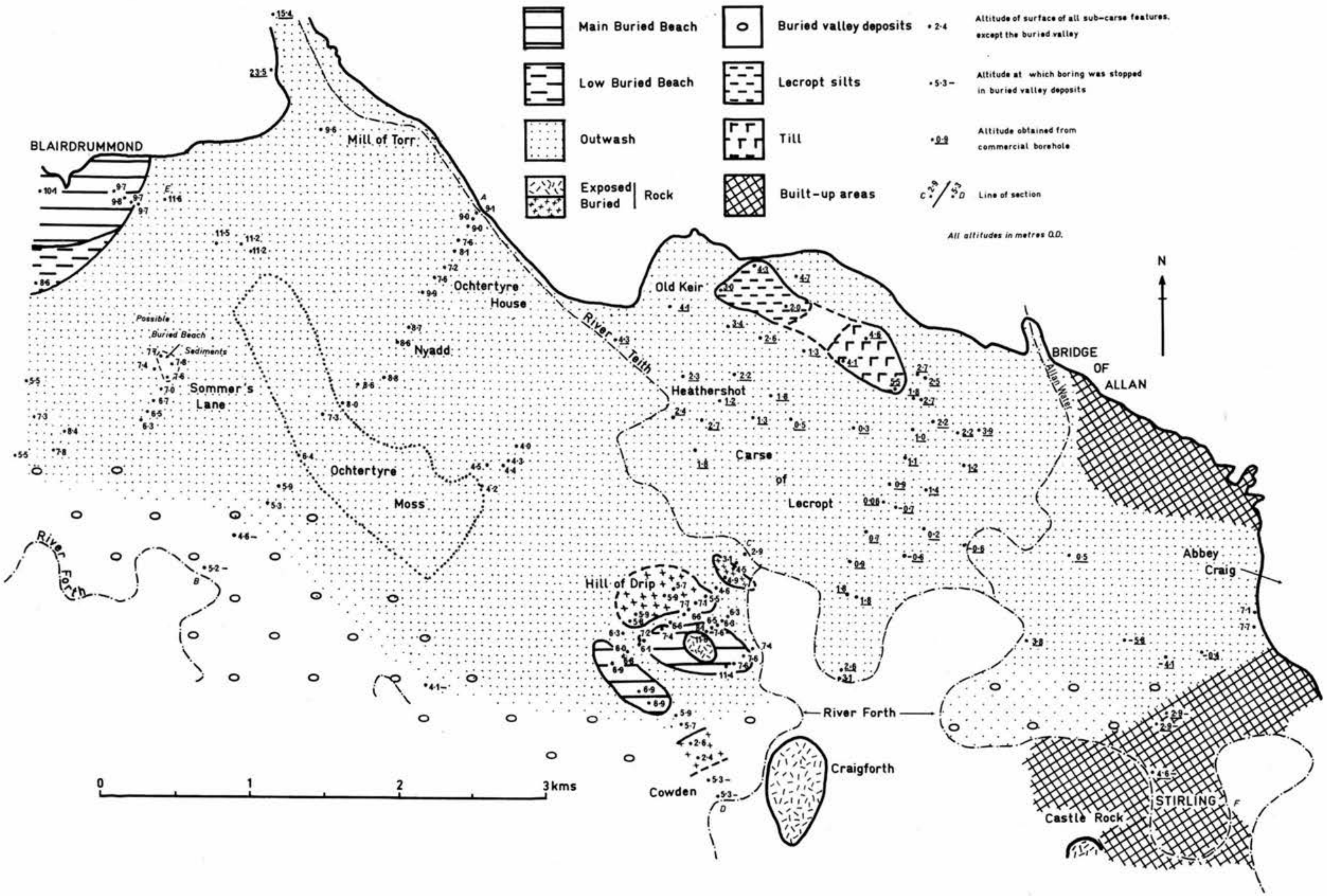
THE STRATIGRAPHY AND SUB-CARSE MORPHOLOGY OF THE AREA BETWEEN BLAIRDRUMMOND AND THE STIRLING GAP*

The carse between Blairdrummond and Stirling takes the form of a subdued clay plain similar in many ways to that already described in the west. From the narrows at Coldoch, it widens to a maximum of almost 5 km in the vicinity of Ochtertyre, only to be limited again at the Stirling gap. On the south it is bounded by the meandering River Forth and near Blairdrummond House the River Teith enters the carse, occupying a shallow valley and flowing in a south-easterly direction until it joins the Forth slightly more than a kilometre west of Stirling. The Allan Water, also slightly incised, meets the Forth nearer the town. To the north the land rises away from the former carse shoreline, often quite sharply, as is the case between the Mill of Tor and Ochtertyre House, where the Teith has helped to produce steep bluffs more than 15 m high and near Bridge of Allan, where the western end of the Ochil Hills is encountered.

Several eminences that must have been islands in the carse sea now protrude through the clay, adding some variety to the landscape. There are three in all, the Nyadd and Hill of Drip composed of Old Red Sandstone and Craigforth of igneous origin, possibly

*Figure IV.1 is applicable to this entire chapter.

Figure IV.2 Sub-carse morphology — Blairdrummond to Stirling



intruded into crustal weaknesses associated with the Ochil Fault which passes between it and the Hill of Drip. The first two stand only a few metres above the general level of the carse compared with the more resistant intrusives of Craigforth rising 60 m above the plain, but it has been suggested (Dinham, 1927) that in "pre-glacial" times all three formed part of the watershed between the glens of the Forth and the Teith. In this area, however, glacial erosion has been significant (Chapter I) and unless it becomes possible to reproduce the "pre-glacial" landscape with some accuracy, Dinham's suggestion must remain unsubstantiated. At Stirling the already narrow plain is further restricted by the presence of Abbey Craig and the Castle Rock in the gap and here the Forth swings towards the northern margin of the carse, limiting its width to a few hundred metres in places while providing a natural eastern limit to the area.

Although the carse east of Blairdrummond is essentially similar to that farther west, there are several important variations. To the observer, the carse at Blairdrummond, Ochtertyre or Lecropt is obviously drier than that at Thornhill and this is accompanied by a greater thickness of the carse crust in the first three areas. No accurate measurements were taken but field observation showed that in the vicinity of Thornhill, the crust is normally less than a metre thick, while to the east it commonly exceeds this figure. Where a thicker, tougher carse crust is accompanied by a general toughening of the carse-clay, penetration becomes very difficult if simple handboring techniques are used. Indeed, in the Carse of Lecropt it proved impossible to reach the sub-carse deposits in all but a few cases, due to the impenetrability of the carse-clays. In this area, however, numerous commercial boreholes were available for consultation.

The thicker crust and generally increased toughness of the clay between Blairdrummond and Stirling appears to be associated with the drier conditions produced by improved drainage. In well drained arable land or close to ditches and streams the crust increases in thickness whereas in poorly drained areas, near the remnants of the once extensive peat mosses, for example, the crust is very thin or even non-existent. In turn, the variations in drainage are related to several factors that include history, morphology and stratigraphy.

In common with most of the carselands west of Stirling, the area at present under consideration was once covered with a blanket of peat moss. Early agriculturalists undoubtedly removed some of this cover, particularly around the edges where it was relatively thin, but it was during the late eighteenth century and into the first half of the nineteenth that the great clearances took place, the peat being removed to expose the potentially rich clay beneath. The efforts of the improvers were such that in the 25 sq km of carseland on the north side of the Forth between Blairdrummond and Stirling only the relatively small moss at Ochtertyre remains, covering an area of slightly more than a square kilometre. At the same time numerous deep ditches were cut across the area to carry off excess water to the Forth or Teith and in the century since the improvements this part of the carse must have dried out considerably helping to produce the thick crust and tenacious clay encountered today. On the other hand, to the west, in the Thornhill area, the moss clearances were less extensive and some 12 sq km of peat remain in Flanders Moss acting as a natural reservoir and helping to prevent the carse from drying out in the same way as it has to the east. Thus, it would seem that historical factors are partly responsible for variations in the carse east and west of Blairdrummond.

The presence of the River Teith no doubt also helps natural drainage. West of Blairdrummond a depression is often encountered along the back edge of the carse and this allows excess moisture to collect, encouraging the persistence of a peat cover. Near Ochtertyre, the Teith aids drainage as it flows for 3.0 km along the northern edge of the carse in a flood-plain that lies below the general surface level. The driest part of the area is the Carse of Lecropt, bordered on three sides by the Teith, Forth and Allan Water and this is reflected in the consistency of the carse-clays. It can also be noted that the wettest area is that midway between the Forth and Teith in a location that must have been difficult to improve during the clearances for it is now occupied by the remains of Ochtertyre Moss.

A final factor that appears to affect the toughness of the carse in this area is the nature of the underlying deposits. The sub-carse deposits here consist chiefly of sand and gravel which contrasts markedly with the situation to the west where the silts and sands of the buried beaches are most common. The increased porosity of the gravel would allow easier drainage than relatively compact silty sand or clay and it is suggested that this is a further reason for the tough nature of the carse-clays of this area. It can be noted also that east of Stirling where the buried beaches are again more extensive the carse is generally softer and more easily penetrated.

Although certain obvious differences exist between the Blair-drummond-Stirling area and adjacent parts of the carse, in terms of agricultural geography and morphology it is only when the stratigraphy is examined that a more important difference comes to light. The buried beaches that are so conspicuous in the Thornhill area are of extremely limited extent here, their position immediately beneath the carse being taken by widespread sand and gravel deposits. These can be followed for some 7-8 km in an east-west direction and in all cover an area of 25 sq km, contrasting with the few hundred square metres of buried beach sediments in this area.

Information on the sub-carse deposits is provided by 290 bore-holes, most of which reach only as far as the surface of the buried gravel due to the limitations of the Hiller borer. However, in the Carse of Lecropt 75 recently completed commercial boreholes give a description of the composition and thickness of the gravel, while a further five provide information on the area from which the Teith enters the carse. Apart from those at Lecropt, both hand auger and commercial boreholes are generally unevenly distributed. A traverse from Ochtertyre House in a south-westerly direction through the Nyadd towards the Forth accounts for 45 holes while 73 are located in the vicinity of the Hill of Drip because of the complexity of the deposits at that point. The remainder are located according to no set pattern, but at points where earlier investigation showed that they might provide useful information.

An early reference to the buried gravel is to be found in the Old Statistical Account of Scotland for the parish of Kincardine, published in 1791 (Chapter I). There, the chronicler refers to the gravel and notes that it dips towards the Forth with a gradient of one in one hundred, but fails to mention its altitude or overall distribution. The present investigation shows that, from a high point near Blairdrummond, the gravel slopes south, east and west, taking the basic form of an asymmetrical fan with its apex at the mouth of the Teith valley and its eastern margin elongated through Lecropt as far as Stirling. On its southern edge, the fan is limited by the buried valley of the Forth although in places the margin is very indistinct for the finer deposits of the fan are similar to those of the buried valley. The presence of shell fragments in the latter aids differentiation, but they are not always encountered.

Followed northwards into the valley of the Teith, the gravel passes out from beneath the carse-clay to form river terraces that are considered to have been produced by the deposition and dissection of outwash (Smith, 1965). This being so the buried gravel can be regarded as fluvioglacial material carried out into the Forth valley in the form of an outwash fan, elongated in the direction of the Stirling gap. In accord with a fluvioglacial origin is the variability of the deposit which can change from large gravel to coarse sand to mixed sand and gravel in a relatively short horizontal distance. In addition, the sediments appear to become finer away from the apex of the fan. This is most obvious at Blairdrummond where the deposits near the Teith tend to be large or medium gravel, often quite angular, with the occasional layer of coarse sand while to the south the sand becomes predominant until near the Forth the outwash sediments are very difficult to distinguish from the deposits of the buried valley. It might be expected also that the fluvioglacial material would become finer towards Stirling and this is evident to a certain extent. However, gravel is still found in large quantities at the eastern end of the area. It is possible that the Allan Water has provided some of this, but the amounts involved suggest that this is not the sole cause. The formation of these features together with their age and relationship to the deposits of the Teith valley will be discussed in greater detail in Chapter VII.

Information on the thickness of the sand and gravel proved difficult to obtain for much of the area, due to the limited capabilities of the Hiller borer. However, as noted, a number of commercial borehole logs were made available for the Carse of Lecropt and the area near Stirling. The only deep borehole west of the confluence of the Forth and Teith is a well-bore at Nyadd Farm. Here, the sand and gravel is 3.5 m thick lying on a 4.9 m bed of "clay and stones" (till?) that in turn rests on Old Red Sandstone, rockhead being at 0.5 m O.D. Off the carse and into the Teith valley the gravel is as much as 8.4 m thick but the figures here and at the Nyadd are small compared with those at Lecropt where thicknesses of over 12.0 m are common and a maximum of 19.1 m is recorded. In a case such as this the sand and gravel does not normally form one homogeneous stratum but rather a number of layers varying according to the proportions and size of the constituent particles. For example, in the bore that produced the maximum thickness, the log gives the following description of the strata:-

Stratum	Thickness in metres
9. Soil	0.2
8. Mottled clay	1.7

7.	Grey silty clay	7.6
6.	Loose gravel	2.7
5.	Sand and fine gravel	6.7
4.	Coarse sand	7.6
3.	Sand	2.1
2.	Clay and stones	0.6
1.	Rockhead	

Such a situation is quite common and may reflect several factors such as the changing position of the outwash streams and their varying competence.

Despite the limited number of boreholes penetrating the gravel, sufficient reach its surface to permit a reasonable description of its altitude and form. The greatest altitude is not found at the apex of the fan, as might be expected, but a few hundred metres to the west where a value of 11.6 m O.D. is recorded. This may be explained by erosion caused by the Teith when that river became the dominant path for water from the valley after the major portion of the fan had been formed. An illustration of this can be seen in Figure IV.2 where a former course of the Teith is indicated near the northern end of the traverse. It takes the form of a valley 400 m wide and 2-3 m below the general level of the gravel surface. A further point that emerges from this figure is the relatively level surface of the gravel to the north of the Nyadd whereas to the south of the rock it dips gently towards the Forth. Redistribution of the deposits by the Teith may partly explain this also. A line joining the top of the gravel in boreholes 264 and 252 would continue the general gradient of the surface north of the Nyadd and it seems

THE SUPERFICIAL DEPOSITS OF THE AREA BETWEEN-
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(The location of each section is indicated in Figure IV.1.)

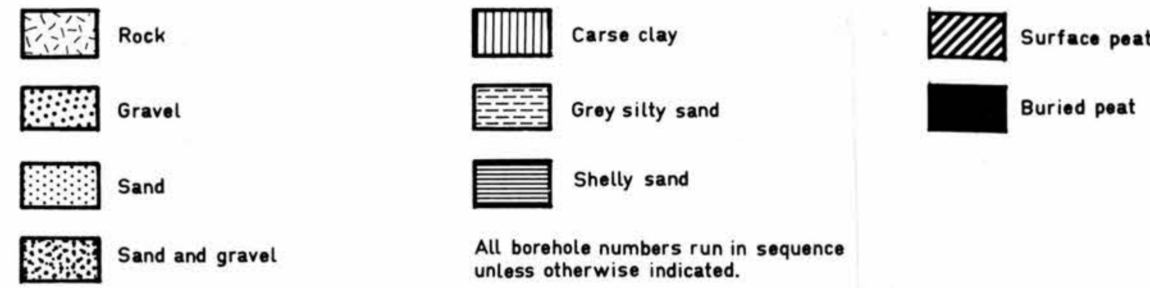


Figure IV.2 Ochtertyre – Nyadd – River Forth

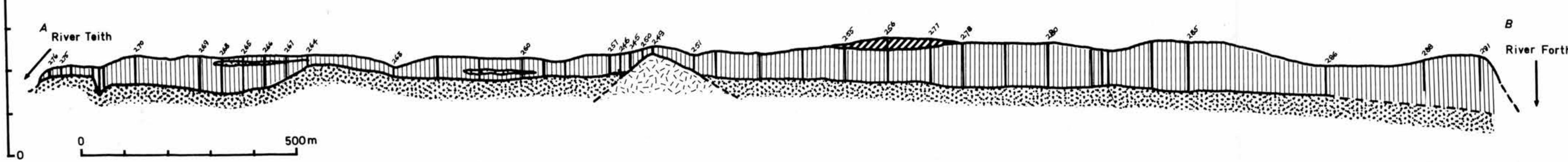


Figure IV.5 Hill of Drip – Cowden

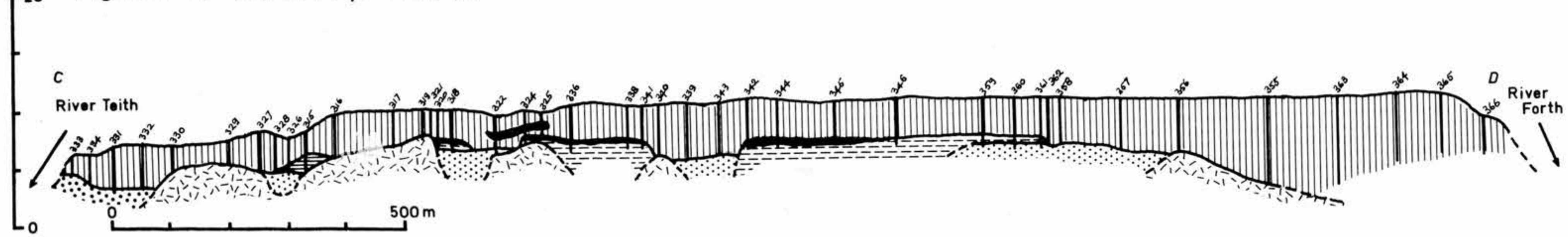


Figure IV.3 Blairdrummond – Stirling (Heights on the surface of the Teith outwash)

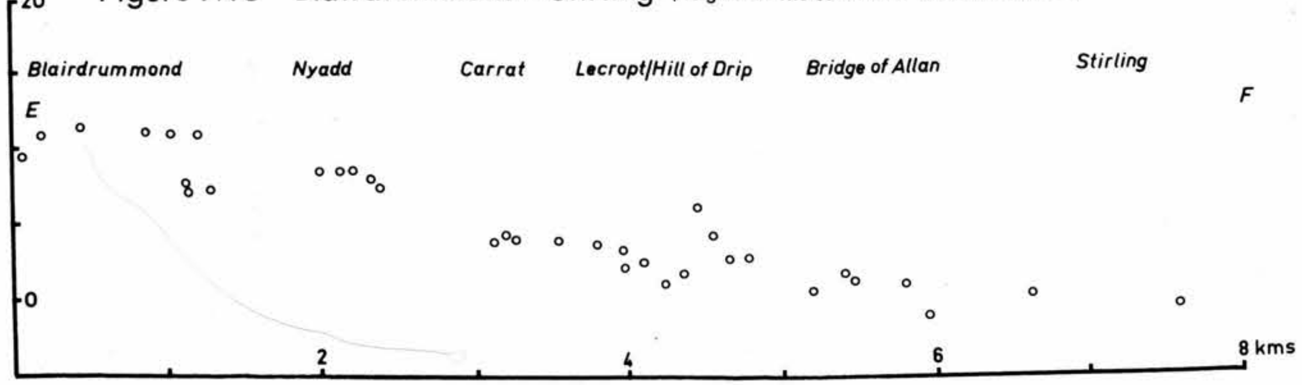
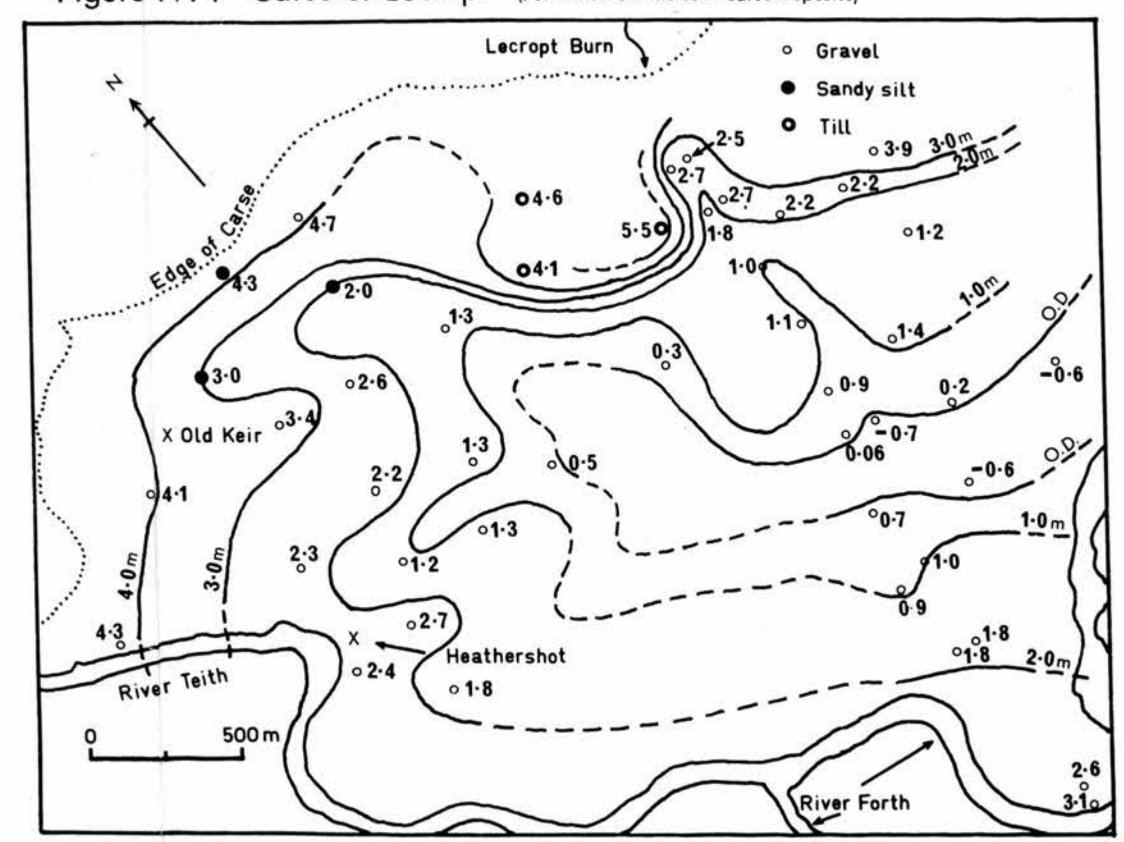


Figure IV.4 Carse of Lecropt (Formlines on the sub-carse deposits)



possible that this situation may have existed at some time in the past, the river later removing some of the deposits to leave the present surface. This suggestion is supported by the presence of sand and gravel lenses in the lowest metre of the carse, showing that the Teith has, in fact, altered its course at different times in the past.

From a height of 9.9 m O.D. near Ochtertyre House, the gravel surface falls away in a south-westerly direction to 8.2 m at the Nyadd, 6.4 m beneath Ochtertyre Moss and a low of 4.7 m O.D. at about 400 m from the River Forth. These figures give an average gradient of one in three hundred which compares with results of one in a hundred or one in two hundred quoted for outwash by Flint (1961). The discrepancy is not serious and may well be explained by the fact that Flint's results do not refer to deposits that have been buried beneath several metres of carse-clay.

As already noted, the highest point recorded on the gravel is 11.6 m O.D., reached near the western limit of the area. From here, the surface slopes quite sharply with a gradient of one in one hundred to the west (Fig.III.9) and has been followed down to 9.5 m O.D. Undoubtedly it descends lower than this, but it could not be located owing to the presence of tough grey silty sand overlying it.

In addition to the southerly and westerly slopes, there is also a marked slope towards the east and this is perhaps the most impressive. It can be traced over a distance of 7 km, as far as Stirling where at a number of points its surface lies below sea-level. Heights recorded along a line running from Blairdrummond in a direction slightly south of east give an indication of the slope.

At Blairdrummond the height of the gravel surface is 11.6 m O.D., but by the time the Nyadd is reached this has been reduced to 8.6 m and within a kilometre of the latter it has fallen to 4.3 m. The slope continues eastwards to 3.1 m at the Hill of Drip, 1.8 m at the southern edge of Lecropt Carse and reaches a minimum of -0.4 m O.D., immediately west of Stirling. It is considered that these figures are representative of the slope involved, but a more comprehensive coverage may be obtained from Figure IV.3.

In the Carse of Lecropt the number and distribution of the boreholes has allowed form-lines to be drawn on the surface of the gravel and this confirms the general eastward slope of the surface of the deposits. Indeed, the slope increases through this area, the surface falling from a height of 4.3 m O.D., in the west, to -0.6 m O.D. near the Allan Water, little more than 2.0 km away to the east. This increase in the gradient is due to the fact that, at Lecropt, the gravel takes the form of a broad, complex valley, the lower altitudes occurring within this valley. Figure IV.4 suggests that at some time in the past, the River Teith continued its course eastwards at Heathershot to produce this valley. In doing so, it may have been aided by water flowing from a valley north-west of Old Keir and from the Lecropt Burn. Presumably, this water went on to meet the Forth, but the exact location of the confluence cannot be determined, for, nearer Stirling, the stratigraphy becomes very complicated, largely due to the effects of the constriction of the valley on erosion and deposition. A whole range of deposits is encountered, from pure gravel through gravel mixed with clay, to sand and gravel and pure sand, all lying beneath a blanket of carse.

They vary in height from -0.4 m O.D. to 7.7 m O.D. and as a result are very difficult to correlate. In addition, the presence of the town limited boring and information had to be obtained from only a few commercial bores. The form of the sub-carse deposits in the vicinity of the Stirling gap, and the relationships between them, is therefore very difficult to establish.

Although commercial boreholes are restricted in their usefulness in many instances, because of missing altitudinal data or lack of locational information, they have the advantage of greater penetration compared with a hand-borer. The Carse of Lecropt borehole logs are most informative in this respect, giving the stratigraphy down to rockhead in several cases. Often the rock-type is not differentiated, but a number of records refer to "sandstone" or more particularly "red sandstone" corresponding to the Old Red strata of the geological maps of the area. The altitude at which rockhead is encountered ranges between 3.8 m O.D. and -19.5 m O.D., with a number of the sub-zero heights located beneath the valley in the sand and gravel, although by no means confined to it. This points to the possibility that the valley was not formed entirely by river erosion and it is suggested that the Teith took advantage of an already existing depression -- probably ice-eroded -- when it followed a more northerly course through this area.

In one or two places, bedrock is overlain directly by gravel, but it is more common for these strata to be separated by other deposits. Of these there are two that are most important. In a total of 35 boreholes penetrating the gravel, 14 show the sub-gravel deposits to be grey or brown sandy silt while 11 refer to firm brown till or firm sandy clay and stones in a similar position. Most logs refer to "till" by name, although those mentioning "firm clay and stones" or "firm sandy clay and stones" were taken to indicate till. Several bores include both deposits and where this is so the till lies beneath the sandy silt.

The former has no obvious pattern to its distribution and it varies in thickness from as much as 9.4 m to as little as 0.6 m, while occasionally it is not present at all. In some cases it is possibly not recorded due to the insufficient depth of the borehole, but in at least six places rockhead is noted without the presence of till. The colour of the till is normally recorded as red and this accords with the solid geology of the immediate area.

With an average thickness of 9.6 m, the sandy silt represents an important facet of the stratigraphy. In addition, these sediments, with some associated clayey sand, cover an area of almost 2.5 sq km and this, along with the thickness and composition of the deposit, suggests formation within a water body of considerable extent. The surface of the sediments shows fairly large height differences, but this may be explained by erosion subsequent to its formation. Whether the sandy silt is lacustrine or marine-estuarine in origin is not clear, for there is no record of varves being present and only one reference to shell fragments associated with it. However, this factor, along with the time of formation of the deposit will be considered more fully in Chapter VII.

In an area notable for the widespread distribution of sand and gravel, a major anomaly is a gravel-free section situated in the northern part of the Carse of Lecropt. Here, boreholes through the carse-clay pass directly into the sandy silt or till that normally lies beneath the gravel. The area is long and narrow -- 1.6 km by 400 m -- with its long axis lying roughly east-west and completely surrounded by gravel. Two basic possibilities exist for an explanation of this feature. Either, gravel was deposited in this area and subsequently removed by erosion, or, for some reason, no gravel was deposited here. In this case, it appears that both possibilities might apply.

Three boreholes in the western part of the gravel-free area show sandy silt or sandy clay immediately beneath the carse while, to the east, till occupies this position. The surface of the silty sand lies at an altitude similar to that of the surrounding gravel and when formlines on the gravel are continued over the silty sand they indicate a valley extending northwestwards beyond Old Keir. It is suggested that the formation of this valley brought about the removal of the gravel. On the other hand, in the eastern part of the gravel-free area, the till stands 2-3 m above the general level of the gravel surface and it seems likely that it remained above the gravel during the deposition of the latter. Thus, despite the general simplicity of the outwash fan, areas such as this make it apparent that this aspect must not be over-emphasised.

Having examined the deposits below the buried gravel, those resting on it can now be considered. It was noted that at Blair-drummond the silty sand of one of the buried raised beaches overlapped part of the western margin of the Teith fan at heights between 9.0 and 10.0 m O.D. Bearing this in mind and considering the fact that large areas of the fan descend below this altitude, it might be expected that at least a moderate proportion of the gravel surface would carry a cover of buried beach sediments. Even taking into account the eastward slope of the beaches, which would limit the area in which they could be deposited, the buried beaches in this area are very small indeed. The reasons for this may not be so complex as would at first appear but they can be more suitably covered below (Chapter VII) and here, the beaches will be examined in terms of location, altitude and composition.

In this whole area of some 25 sq km, buried beach sediments cover no more than a few hundred square metres. Most of this area is located near Hill of Drip with one small patch at Sommer's Lane, Blairdrummond and possibly another at the northern edge of the Carse of Lecropt where grey silty sand is recorded in one borehole at 5.8 m O.D. At Sommer's Lane, grey-green silty sand rests upon medium to large gravel in four boreholes and has an average thickness of slightly over 23 cm. No peat is to be found between the carse clay and the silty sand, but in one case shell fragments are present in this position. The four heights on the surface of the silty sand lie within the range 8.2-7.5 m O.D., which corresponds to a number of heights on the Main Buried Beach between Coldoch and Woodlane.

At Blairdrummond, where the gravel passes below the buried beach sediments, it might be expected that an apron of silty sand would exist as an almost continuous deposit over the margins of the outwash fan, indicating a former incursion of the sea over the gravel. This would take the form of a semi-circular band of grey silty sand along the southern extensions of the outwash from Woodlane to the Hill of Drip. However, between Sommer's Lane and the Hill of

Drip, the silty sand is absent. West of Sommer's Lane, the distribution of boreholes is such that a narrow strip of buried beach may exist between there and Woodlane, although none has been located. If this did exist, it would increase the area of buried beach sediments resting upon the gravel by several hundred square metres, but the total amount would remain extremely small compared with the area of gravel as a whole.

In the vicinity of the Hill of Drip, solid rock is encountered within a few metres of the surface in several places, but the Hill itself is the only point where it rises through the carse. Outwash, represented by coarse grey-brown sand with the occasional patch of gravel, has been deposited around and upon these rocks and in two, possibly three, places the sand takes the form of a channel-fill between rock walls (Fig.IV.5). Of 17 heights obtained on the surface of the sand, 10 lie within the range 6.3-6.7 m O.D., but towards the River Teith, 3 boreholes (326-328) give heights, on sand filling a channel, of 4.3, 4.4 and 4.6 m O.D. The height difference may be associated with the erosional and depositional activities of the Teith, for nearer the river, gravel is encountered at 2.9 m O.D. and, from the form of the carse surface, it is apparent that the Teith has not always followed its present course.

The buried beach deposits of this area rest upon the coarse sand and produce a platform of sediments around the Hill of Drip. A few hundred metres to the south-west lies another patch of sediments, the two being separated by a narrow valley floored with coarse grey-brown sand. It was not possible to verify the presence of the sand in all boreholes, but the succession from carse-clay, through buried peat and grey silty sand to coarse grey-brown sand, occurred in sufficient cases to show that it was meaningful. Where the succession was found, the beach deposits averaged 34.0 cm in thickness, but in other places they have been penetrated to depths of 44.0 and 60.0 cm without the coarse sand being reached. In the majority of cases, however, penetration beyond the upper few centimetres was not achieved, due to the toughness of the silty sand.

The buried beach sediments of this area are essentially similar to those found to the west of Blairdrummond, in terms of both colour and composition. They consist basically of fine grey or grey-green silty sand containing a high proportion of micaceous fragments. The upper few centimetres often contain a considerable amount of clay and this may form a distinct layer in which the clay is predominant (Boreholes 306, 307, 308, 336, 345 and 346). Although the grey silty clay is very similar to that of the Low Buried Beach near Thornhill, the cover is not complete and its distribution is reminiscent of the clay patches on the surface of the Main Beach east of the Goodie Water.

Like the beaches further west, that at the Hill of Drip is covered by a layer of peat. It is a relatively thin layer, seldom exceeding 20.0 cm, but it is extensive, almost entirely covering the surface of the beach. Furthermore, it is commonly a very soft deposit, compared with the buried peat to the west, with little included woody material. Consequently, it is easily penetrated. A lense of peat with a maximum thickness of 67.0 cm, lying entirely within the carse clay, was discovered in boreholes 322-325, apparently having drifted in during the deposition of the clay.

The surface of the buried beach at Hill of Drip has been heighted at 27 points within a relatively small area. Of these heights, 18 lie within the range 7.0-7.9 m O.D., the remaining 9 lying between 6.8 and 7.0 m O.D. To the west, measurements on the Low Buried Raised Beach have produced heights falling into a similar range and at first sight the beach at the Hill of Drip might be placed in that category. Taking isostasy into consideration, however, a slope ought to exist on the Low Beach producing lower heights at Hill of Drip than at Thornhill, some 9.0 km distant. On the other hand, the Main Buried Beach is seen to slope gradually eastwards from 12.5-12.9 m O.D. near the Menteith Moraine, to 9.0-10.0 m O.D. near Blairdrummond. The values at Hill of Drip would continue this trend. This will be examined graphically and statistically (Chapter VIII), but, at this point, taking into account the altitude, form and composition of the deposits at the Hill of Drip, it seems feasible to suggest that they belong to the Main Buried Raised Beach.

A final facet of the sub-carse morphology that can be considered here is the buried valley of the Forth. In this area it is not so marked as farther west, largely due to the presence of the Teith outwash. Towards the southern edge of the fan, the junction between channel and outwash deposits is often very difficult to determine, because of the removal of material from the fan and its subsequent deposition in the valley. Occasionally, the presence of shell fragments allows a distinction to be made. At the eastern edge of the buried beach sediments at the Hill of Drip, the valley is sharply defined (Fig.IV.5) and may have part of its course over solid rock, but beyond this towards the Stirling gap, the nature of the deposition is such that it cannot readily be distinguished.

Conclusion

The carselands lying between Blairdrummond and the Stirling gap are superficially little different from those west towards the Menteith Moraine. However, an examination of the stratigraphy and sub-carse morphology shows a distinctly different area. The following are the main sub-surface features that have been identified:-

1. An outwash fan of coarse sand and gravel, sloping out in all directions from its apex near the mouth of the Teith valley, but attenuated in an easterly direction. From a maximum height of 11.6 m O.D. at Blairdrummond, it slopes eastwards to pass below Ordnance Datum near Stirling. Commercial boreholes indicate that this buried gravel in places masks areas of fine water-laid sediments and till.

2. At Blairdrummond, the western edge of the outwash is hidden beneath the deposits of the Main Buried Raised Beach, indicating the relative age of the two features. The Main Beach has also been identified at the Hill of Drip at heights between 6.8 and 7.9 m O.D. Other patches of beach sediments occur, but to a very limited extent and a characteristic of the area is the general absence of these deposits.

CHAPTER V

THE STRATIGRAPHY AND SUB-CARSE MORPHOLOGY OF THE AREA BETWEEN THE STIRLING GAP AND KINCARDINE-ON-FORTH*

Beyond the limits imposed by the Stirling gap, the carselands again become extensive, particularly south of the River Forth, where an unbroken expanse of carse-clay, 3.0-5.0 km wide, stretches from Stirling to Grangemouth. In contrast, the northern section is rather limited, attaining a maximum of 4.0 km a short distance east of Stirling, before branching to send one narrow arm into the valley of the River Devon and another, nowhere exceeding 2.0 km wide, along the north bank of the Forth as far as Kincardine. The considerable difference in area that this produces is evident from Figure I.1.

Along its northern margin, the carse lies against the Ochil Hills which rise sharply to heights of 350.0-500.0 m above the plain and extend along its edge from Airthrey to Tillicoultry in the Devon valley. The southern arm, between Cambus and Kincardine, is backed by a variety of features, including Carboniferous rock outcrops as well as glacial and raised marine deposits in places. The Forth, providing the southern boundary, changes considerably as it flows eastwards. Between Stirling and Alloa it traces its normal meandering course, becoming gradually wider, but beyond the latter it straightens,

*Figure V.1 is applicable to this entire chapter.

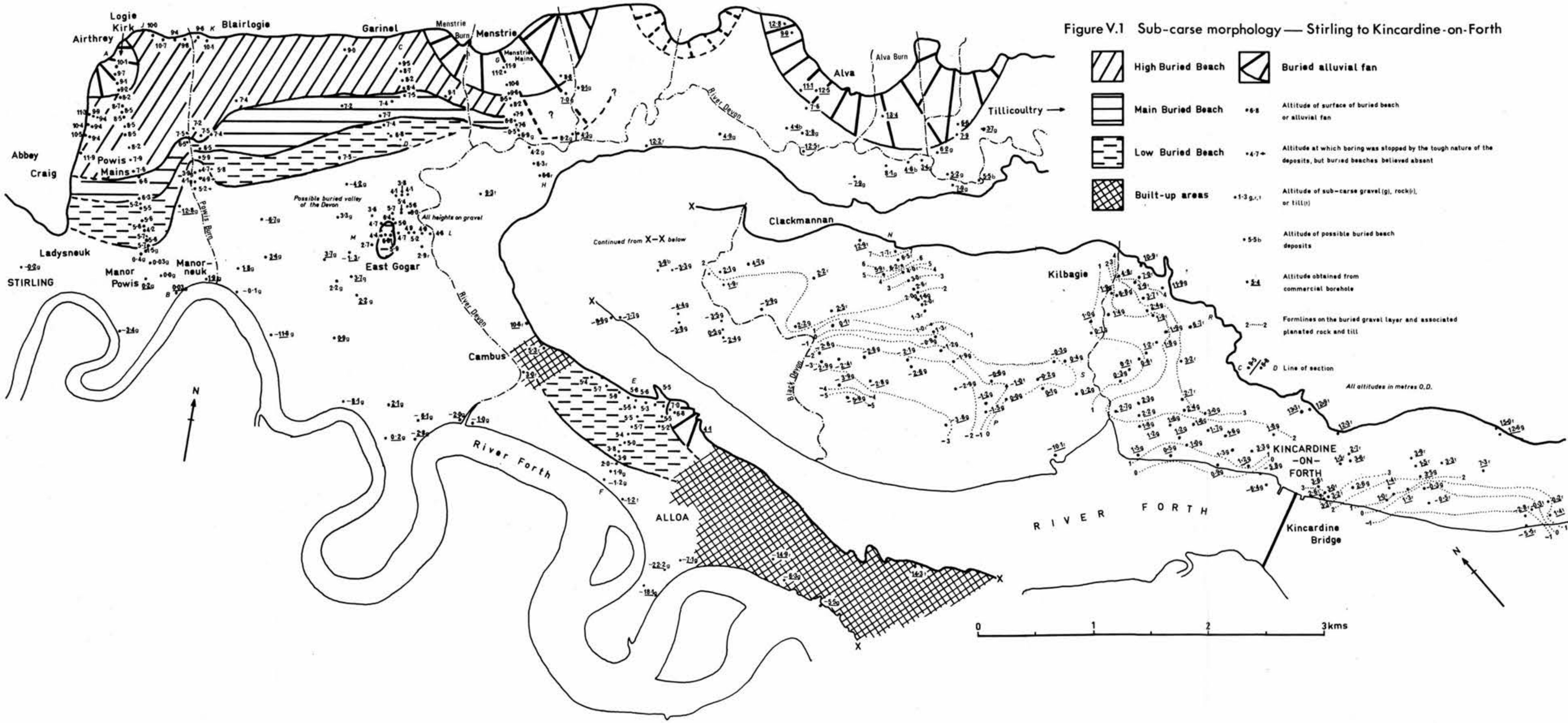


Figure V.1 Sub-carse morphology — Stirling to Kincardine-on-Forth flowing south-eastwards to Kincardine where it widens significantly to become obviously estuarine. For the whole of its passage through the area, the river is tidal.

At first sight, the carse in this area is basically similar to that already described west of Stirling. Closer inspection, however, shows that a number of important differences exist. Smith (1965, 1968) has shown that the surface consists of a number of facets related to different sea-levels in Postglacial times. Several of these have been recognised west of Stirling also, but the differentiation is especially distinct east of the town where a sharp break of slope runs north-eastwards from Abbey Craig towards the Devon valley and another is evident near Cambus. Thus, immediately east of Stirling, before the plain divides, the carse consists of two distinct surfaces, designated Postglacial 2 and 3 by Smith.

Superimposed on this basic division there are other features mainly associated with the dissection of the surfaces. The higher of the two surfaces -- Postglacial 2 -- is strongly dissected, particularly in the vicinity of Menstrie where a number of channels cross the carse in a general north to south direction. Erosion is also evident on the lower surface, but to a lesser degree, and channels originating on the upper terrace often end abruptly at its southern edge or may be continued on the lower surface by much smaller channels. Beside the Forth the carse has been eroded by the river as periodic changes in course have taken place. Below Abbey Craig a large meander scar has been cut in the carse showing that the Forth once flowed almost to the base of the rock.

As well as causing erosion of the carse edge, the Forth has been responsible for deposition in this area, as can be seen near the river, where a considerable proportion of sand is incorporated in the normally clayey carse sediments. Along the northern margins of the plain there is further evidence of deposition. Streams from the Ochil Hills have carried sand and gravel out on to the carse surface, forming a series of alluvial fans at the junction of hill and plain. In times of flood, detritus from the fans may be spread over the carselands, even yet, as stream courses change, but on the larger fans, as at Menstrie and Alva, restriction of the streams by artificial means has reduced this.

In the Devon valley, these fans play an important part in the morphology of the area. At Alva a large fan, extending fully 800.0 m into the valley and more than a kilometre wide, restricts the carse to a few hundred metres in width, while a feature of similar dimensions at Tillicoultry effectively marks the eastern limit of the carse in the valley. Material carried down from the hills by these streams, has been incorporated in the carse-clays producing a tough, relatively sandy deposit, while the Devon itself has been responsible for the deposition of sand along its banks. In the New Statistical Account of Scotland (1841), a similar situation was noted. The chronicler for the Parish of Alva recorded four types of arable soil, reading from the Ochils, in a southerly direction, as follows:-

1. Rich hazel mould, mixed with gravel and small stones.
2. Stratum of moss over a bed of clay, extending from 50-100 yards wide and the moss in some places, 7 feet deep.
3. Strong clay.
4. Haughing ground with sand laid down by 2-3 inundations of the

Devon per year.

In addition to the coarser sediments along the northern edge of the valley and along the river, the presence of the moss is of considerable interest, for, this is the only part of the area east of Stirling and north of the Forth that appears to have carried peat. Elsewhere there is no evidence for a peat cover except along the edge of the Ochils, where thin peat is still present today (Smith, 1968).

Near Menstrie, the Devon leaves its valley and turns sharply southwards across the carselands to meet the Forth near Cambus. In this section, the river follows a meandering course and there is ample evidence that it has changed position a number of times. Near East Gogar a particularly well developed meander scar is encountered with coarse sandy deposits at its base and in the arc between it and the present river course (Boreholes 566, 567 and 568). Adjacent to this, sandstone is present in the bed of the river. In places, an attempt has been made to maintain the Devon's present course by strengthening the banks and building artificial levees. This is evident near East Gogar and at the confluence of the Devon with the Forth.

Eastwards from Cambus, the northern carselands are relatively narrow and consist, according to Smith (1968), of a surface transitional between the two lowest carse levels as well as a surface representing the lowest level, namely Postglacial 4. In addition, near Kincardine, a limited area of reclaimed land is encountered near the river and this is very similar to the carse in terms of composition and texture, although at a lower altitude. These features are not always readily distinguishable without some form of measurement and in this region in particular, the carse surfaces are increasingly obscured or interrupted by industrial activity or by the expansion of the towns of Alloa and Kincardine. Coal mining has been of considerable importance here since the mid-19th century and indeed from Stirling eastwards there is evidence for this in the form of increasing mining subsidence which is pronounced between Stirling and Alloa as well as in the vicinity of Kincardine. Such a situation imposes problems involving the measurement of the carse surface and the correlation of sub-carse deposits. However, the mineral and industrial activity was often preceded by extensive borehole investigation, which has led to the availability of a large number of borehole logs for the area.

The sub-surface investigation of this area is based on 236 shallow boreholes used in conjunction with some 250 commercial boreholes, provided by the Geological Survey and local authorities. Certain problems arose with the commercial bores mainly with reference to missing altitudinal information and individual interpretation of strata. The former was resolved by comparison with heights obtained in the measurement of the shallow bores and although these do not have the accuracy of levelled heights, it is considered that the majority of the estimated values lie within ±0.3-0.5 m of the true height. In the case of the stratigraphical interpretation, the problems were often more involved. Due to individualistic recording by different observers it was found that boreholes separated by only a few metres bore no apparent relationship to each other. In some cases, two deposits referred to by the same name, for example, "clay with stones", in adjacent boreholes, were not always the same deposit as altitude and position in the stratigraphical column showed. Where this was so and the borehole coverage sufficiently extensive, it was usually possible to resolve the differences, but not in every case. In a number of borehole logs, the sub-carse deposits had to be combined as "drift" leaving the borehole suitable only for the estimation of the height of rockhead.

Despite these difficulties, the borehole logs give a good indication of the distribution of the various sub-carse deposits. Buried raised beach sediments again make an appearance on a scale similar to those west of Blairdrummond, but here, their morphology is much more varied and their relationship to each other much more complex than in the area previously described. Coarser deposits associated with the Devon and the numerous minor streams issuing from the Ochils are widespread, while farther east towards Kincardine, gravel, till and solid rock are encountered immediately beneath the carse-clay.

The most extensive of the buried beach sediments is the pink silty sand of the High Beach. Bounded on the west by the high ground between Abbey Craig and Airthrey, the beach extends for 4.0 km along the base of the Ochils before dying out against the buried extension of the Menstrie alluvial fan. It reaches a maximum width of almost 1.0 km near its western end but gradually narrows eastwards until at Menstrie it is little more than 100.0 m wide. Like the High Beach near Thornhill, penetration with the Hiller borer beyond the upper few centimetres is virtually impossible and as a result no estimate of the general thickness of the deposit can be made. Along the inner margins of the beach, the silty sand thins out and the underlying sediments can be reached, but obviously such conditions are not representative of the deposit as a whole.

The composition of the pink beach in this area is variable. Near the Ochils and along the inner margin, in general, the deposit can be recorded as "coarse pink silty sand" very similar to the sediments of the High Beach west of Blairdrummond. In places, the silty sand is more brown than pink and this, together with the coarse nature of the deposit, appears to have been brought about by the addition of material carried down from the Ochils as the High Beach was being formed. Away from the backslope, towards the southern edge of the beach, boreholes still record the presence of pink silty sand but much finer pink clay is increasingly encountered. Although no sharp boundaries can be drawn between the areas of pink clay and the areas of pink silty sand, the general distribution of the two deposits is largely to be expected, showing as it does, an increase in the proportion of coarse sediments as the former shoreline is approached. The pink clay is most common on the western portion of the beach where it is widest. Farther east, as the beach narrows and the outer edge is effectively closer to the source of coarser materials, in the hills and the Devon valley, pink or brownish-pink silty sand supplants the clay.

A characteristic feature of the High Buried Beach, as described in the Thornhill area, was the presence of a grey coloration in the upper few centimetres of the otherwise pink beach. This is repeated in the area now under consideration, where the grey colour is commonly restricted to the upper 15.0-20.0 cm. It has been suggested that this does not represent a separate deposit, but rather indicates a modification of the upper portion of the beach by some agency such as weathering (Sissons, 1966) and there is evidence for at least the first part of this statement, in the High Beach east of Stirling. Firstly, there is a close continuity between the two sediment types, as far as composition is concerned. Where the beach consists of pink clay, the upper grey portion is invariably clay also and, where pink silty sand is the main deposit, the uppermost part is composed of grey silty sand. This can be seen in the borehole logs, but when seen in section the relationship is more obvious. In the wall of a ditch opened up during the laying of a pipeline near Menstrie, the beach and associated deposits were exposed over a lateral distance of 2.0-3.0 m (Fig.V.2). Beneath the carse-clay and some surface sand, a layer of compressed vegetable matter, no more than 2.0-3.0 cm thick covered the 10.0-15.0 cm of grey silty sand and passed rootlets through it into the pink sediments below. Inspection showed the junction between the upper grey and lower pink silty sand to be somewhat diffuse, the grey colour gradually giving way to the pink. In addition, the junction was not straight, but took the form of a wavy line as if grey stain had been poured on to the surface and seeped through into the beach before drying. Taking the above evidence into account it appears that the grey silty sand can be regarded as an integral part of the High Buried Beach, the coloration being due to weathering or perhaps leaching that took place while the beach formed a land surface prior to its flooding by the carse sea.

Almost everywhere, the High Beach carries a peat cover that is normally very soft with only a few patches of woody material. In a number of places, the upper few centimetres of the peat are mixed with the overlying carse-clay but the junction of the peat with the buried beach sediments is usually quite sharp. The thickness of this peat layer varies from place to place, but there is a distinct pattern to the variation. Its greatest thickness is recorded near the western end of the beach where it exceeds one metre in a number of boreholes near Powis Mains. Followed eastwards a gradual thinning of the buried peat takes place, through an average of 40.0 cm at Blairlogie, down to 10.0 cm at Garinel and less than 5.0 cm at the eastern end of the beach. The possibility exists that this gradual thinning of the peat is related to changes in the composition of the buried beach. It has been pointed out above that the western part of the beach contains a considerable proportion of clay while towards the east, coarser silty sand is encountered. It is suggested that the relatively poor drainage of the clay areas, as compared with the areas of silty sand, would encourage a thicker growth of peat on the former.

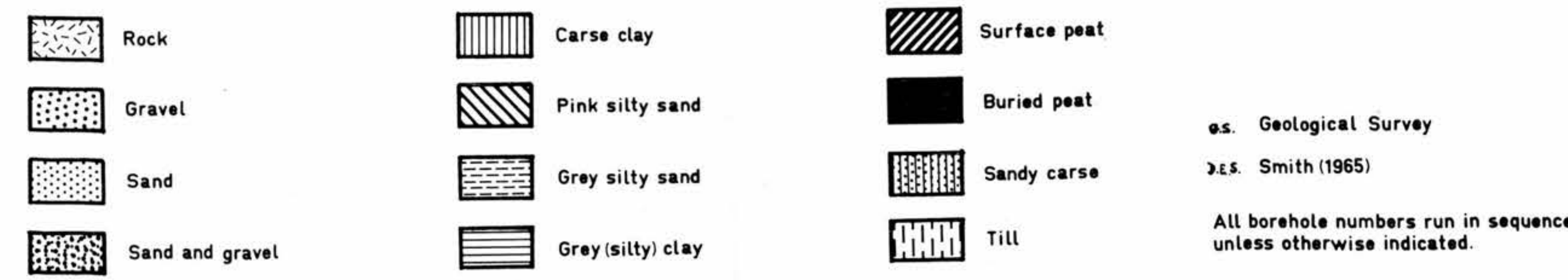
Measurements at, or near, the back edge of the beach show that a maximum height of 10.7 m O.D. is reached between Logie Church and the village of Blairlogie. Most heights in the western part of the area, however, fall within the range 9.4-10.4 m O.D. One kilometre east of Blairlogie, the beach lies at 8.7 m O.D. and at Menstrie it has fallen further to 7.9 m O.D. Between Logie and Abbey Craig, the former shoreline trends roughly north-south and here heights lie between 9.4 and 9.9 m O.D. Along its southern edge, the height of the beach varies between 7.7 m O.D. in the west and 7.3 m O.D. near its eastern end.

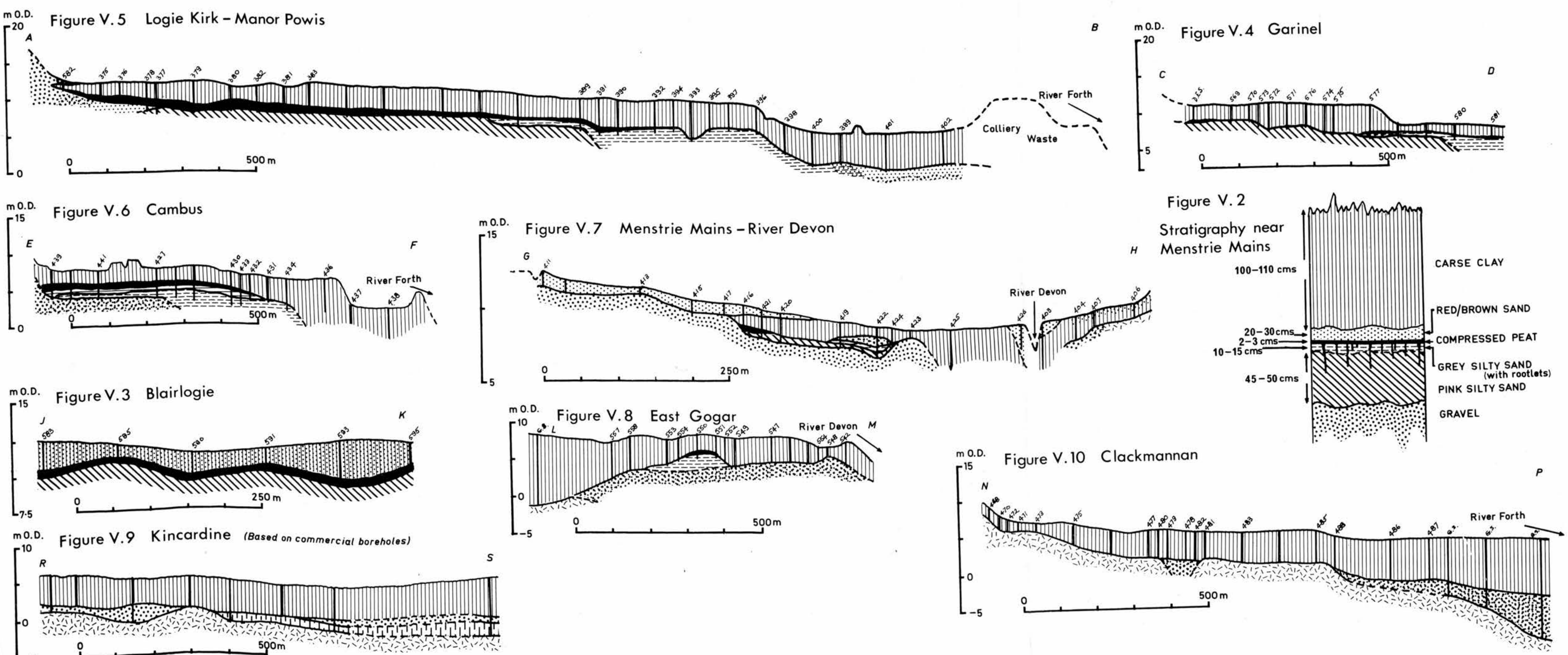
Superimposed upon this general distribution of heights are a number of points where the surface shows considerable variation over short distances (Figs.V.3 and V.4). Two factors appear to explain this. In the first place, while the beach was in the process of formation, the nature of the backslope, with its steep gradients and numerous streams, must have led to the deposition of large quantities of relatively coarse material along the shore. Thus, although the figures quoted above indicate a general slope from west to east -- a slope that might be expected from a consideration of other Late and Postglacial raised beaches in Central Scotland -- there are local irregularities that should be taken into account when the shoreline is being examined. Away from the shoreline itself, erosion has played a part in disrupting the surface of the beach. This is perhaps best seen in the section at Garinel (Fig.V.4) where dissection is particularly strong. Marine activities seem to have been effective at the beach's southern edge, but it is also possible that at least some of the erosion was caused by streams flowing from the Ochils across the High Beach in much the same way as the present streams flow across the carse, and the Powis Burn shows evidence of this in the form of a buried gully where it crosses the outer edge of the beach.

At a point some 150.0-200.0 m inside the southern limit of the High Buried Beach it is not uncommon for a sharp change in height to take place (Figs.V.4 and V.5). Although the elements of the stratigraphy remain essentially the same, changes take place in the thickness of particular deposits and the surface of the beach diminishes in absolute height by 0.3-1.0 m. The normal stratigraphy of carse-clay and buried peat overlying buried beach deposits of

THE SUPERFICIAL DEPOSITS OF THE AREA BETWEEN – STIRLING AND KINCARDINE – ON – FORTH

(The location of each section is indicated in Figure V.1.)





grey and pink silty sand is still present but the layer of grey silty sand is usually thicker. On the higher part of the beach the grey deposit reaches a maximum thickness of 15.0-20.0 cm but is often less, whereas on this lower portion, thicknesses of over 30.0 cm are commonly recorded, with a maximum of 48.0 cm. It is suggested that the grey silty sand on this lower part of the High Buried Beach is of different origin from that on the main, upper portion.

The stratigraphy indicated above is present over a north-south distance of never more than 200.0-300.0 m beyond which the grey silty sand is still present but at a slightly lower level, and the sediments of the High Beach are no longer encountered. A number of boreholes, put down to depths of more than a metre below the normal level of the pink silty sand failed to locate it. It is possible that the pink sediments are present at even greater depths, but, by comparison with the High Beach in other localities this is considered unlikely. The grey silty sand, with isolated patches of grey clay on its surface, extends for several hundred metres beyond the edge of the pink deposits, before ending equally abruptly.

Considering the position and relationship of these deposits, it is evident that two beaches exist along the southern edge of the High Beach. The higher of the two would seem to indicate a period of erosion during which a step was cut in the pink silty sand and covered by a layer of grey silty sand. Subsequently the sea-level fell by 0.3-0.5 m to produce the lower beach. These two beaches, while differing in stratigraphy and composition from the lower beaches in the west, occupy a similar position to the latter with respect to the High Beach and for this reason the composite feature overlying the edge of the High Beach east of Stirling has been provisionally equated with the Main Beach and the lower feature with the Low Beach. Further discussion on this point will be presented in Chapter VII.

The Main Buried Raised Beach is relatively limited in extent east of Stirling, being no more than 300.0 m at its widest point. It stretches from Abbey Craig in a direction slightly north of east for nearly 4.0 km before ending against the alluvial fan of the Menstrie Burn. The grey silty sand, of which the beach surface is composed, bears a strong resemblance to that forming the Main Beach in the west, but the pink silty sand underlying the grey appears to have no counterpart in the west. It might have been expected that the period of erosion that accompanied the formation of the Main Beach east of Stirling would have manifested itself in a similar way west of Blairdrummond, where the buried beaches are extensive. However, the junction of the High and Main Beaches in that area is marked by the buried valley of the Goodie Water and this could have destroyed any evidence that existed. Furthermore, the isostatic recovery of the High Beach prior to the development of the Main Beach would produce a greater height differential between the two in the west than in the east, lessening the likelihood of erosion in the former area.

Like the Main Beach, the Low Beach in this area is of no great extent. It occupies a narrow strip, no more than 400.0 m wide, along the edge of the Main Beach and extends eastwards to the vicinity of the Menstrie fan where it loses its identity in the complex stratigraphy associated with that feature. In addition, a small area of grey silty sand and clay near East Gogar reflects the characteristics of the main body of the beach although well separated from it. The Low Beach is composed mainly of grey silty sand similar to that of the Main Beach. A distinction can be made, however, for the upper few centimetres of the former are often rich in clay. In places, the clay stands out as a separate layer distinct from the silty sand beneath and, although the cover is by no means continuous, thicknesses of as much as 35.0 cm have been recorded.

Over both lower beaches there is a thin and very variable cover of peat no more than 20.0-25.0 cm thick, but commonly much less. This layer is soft for the most part with little woody material, suggesting that its thin nature is due to the lack of development rather than compression by the overlying carse-clay. On the whole, the buried peat in this area is thinner than that on the lower beaches west of Blairdrummond and this may be related to the earlier incursion of the carse sea in the east.

Both the Main and Low Beaches have been heighted at several points along their respective shorelines and they show a pattern that is difficult to reconcile with that expected for the area in general and the beaches in particular. The values indicate a slight increase in height from west to east in both cases. Near Powis Mains, for example, the Main Beach shoreline stands at 6.6 m O.D., but rises to 7.4 m O.D. in less than a kilometre to the east, until at Garinel a maximum of 7.7 m O.D. is attained. This trend is mirrored in measurements from the Low Beach shoreline, which rises from 5.7 m O.D. to 6.8 m O.D. in the same distance and direction.

In an area such as this where isostatic compensation has produced a slope on the Postglacial raised beaches from west to east (Smith, 1968), it would be in order to postulate a similar slope on earlier beaches. This does not seem to follow in the present case. The uneven distribution of heights, with the greater proportion on the western part of the beach, probably mitigates against too much emphasis on a rise to the east, but there is definitely no evidence for the slope to the east that might have been expected.

The activities of the River Devon may possibly explain this apparent anomaly. At the time of formation of the Main Buried Beach the addition of material at its eastern end by the river may have produced a slope towards the west and since that time the cumulative effects of isostatic recovery have been insufficient to eradicate this trend. It can be argued that the High Beach being in a similar situation should exhibit a similar slope. However, during its development material appears to have been supplied by streams and possibly mass-movement all along the face of the Ochils and the relative importance of the Devon was therefore less. Furthermore, accepting the earlier formation of the High Beach, isostatic recovery, having longer in which to be effective, would have reduced or perhaps even reversed the original slope.

These stretches of buried beach sediments along the southern edge of the Ochil Hills form the main examples of that type of deposit in the area between Stirling and Kincardine. As with the High Beach, there is no evidence that the lower beaches extend into the Devon valley as recognisable entities. In a few commercial boreholes -- no more than six -- buried beach sediments may be represented by patches of grey clay or silt with surface heights estimated at between 5.0 and 7.0 m O.D. and in two cases overlain by peat. Although isolated, all lie close to the present course of the river and may indicate remnants of the Main or Low Beaches. The presence of abundant gravel from the Ochil fans could have prevented the penetration of the sea into the valley, except along a narrow strip adjacent to the main river where grey silty sand and clay was deposited. With the eventual return to a lower sea-level, the Devon could have dissected the sediments to produce the present distribution.

Beside the Forth, between Cambus and Kincardine, only one rather limited area of buried beach has been located. East of the junction of the Devon with the Forth, a patch of grey silty sand and clay lies beneath the northern edge of the carse near Cambus. It has an east-west extent of slightly over one kilometre and a maximum width of some 600.0 m. However, the eastern and western limits have not been located exactly and this illustrates the problems involved in boring in industrial or built-up areas. On the west, the presence of the village of Cambus prevented hand-boring but a combination of excavations within the built-up area and boreholes to the west of it shows that the western edge of the beach must lie somewhere beneath the village itself. On the east, playing fields and railway marshalling yards on the outskirts of Alloa forced an estimation of the eastern limit. Despite this, the area in which the beach was examined supplied sufficient information to enable its composition and form to be noted (Fig.V.6).

A characteristic of the beach sediments in this area is their soft nature, allowing considerable penetration and in a number of boreholes permitting the underlying deposits to be reached. Typically the stratigraphy is arranged as follows:-

5. Carse clay
4. Peat
3. Grey (silty) clay
2. Grey silty sand
1. Sand and gravel

The carse, although relatively easily penetrated, contains a considerable proportion of sand mixed with the clay especially near its inner margin. Shell fragments are also common, either scattered indiscriminately throughout the clay or arranged in beds consisting of shell fragments and sand particles. The former situation is most common, but in eleven boreholes in a very small area the shells lie in recognisable beds with absolute heights ranging between 3.7 and 7.1 m O.D. but with a much smaller variation of 6.1 to 7.1 m O.D. in seven of the holes. The shell fragments are normally of sufficient size to allow recognition and *Ostrea*, *Mytilus* and *Cardium* have been identified, the last two being most common.

A thick bed of peat averaging 58.0 cm lies beneath the carse. It forms a complete cover on the surface of the buried beach deposits and attains a maximum thickness of 99.0 cm. In a number of boreholes the peat is very woody but apart from this it is normally soft with the seed heads and stems of *Juncus* as one of the more easily recognisable constituents. A marked transition zone of as much as 10.0 cm of mixed peat and clay is a common feature of the junction between the peat and the overlying carse-clay but the lower boundary with the grey clay of the buried beach is usually quite sharp with only occasional mixing.

The buried beach sediments in this area consist of two distinct types of deposit. Immediately beneath the sub-carse peat is a layer of soft grey clay or silty clay while beneath this again lies a grey silty sand stratum similar to the deposits forming the Main Buried Beach farther west. With an average thickness of 70.0-75.0 cm and a maximum of over a metre, the grey clay lies in a thick blanket over the silty sand. The cover is virtually complete and only in a few holes near the southern edge of the beach is the clay absent. As well as indicating the thickness of the clay, the bore-holes also indicate the remarkable homogeneity of the deposit in terms of colour and composition. Only in the lowest few centimetres does it change somewhat, becoming slightly coarser as some mixing with the underlying silty sand occurs. Elsewhere it remains soft, sticky, grey clay, not unlike carse clay and very reminiscent of the grey silty clay of the Low Buried Beach near Thornhill.

Measurements taken at eleven points along the back of the beach in a distance of almost one kilometre, show that the surface of the grey clay varies in altitude between 5.9 and 5.3 m O.D. Certain groupings of the figures indicate a slight slope from west to east but with regard to the distance and number of heights involved it would not appear to be meaningful. However, the bore-holes do show a slope on the beach from back to front, producing a height difference of over a metre, the altitude of the outer edge of the feature being as low as 4.5 m O.D.

At the southern edge of the beach, a layer of grey silty sand passes from beneath the clay and as already noted this is a significant feature in the stratigraphy. It lies beneath the grey clay throughout the area except in the narrow band near the southern limit of the beach deposits where the clay dies out and the silty sand lies immediately beneath the carse. As noted the silty sand is normally grey in colour, but in a number of boreholes it takes on a definite pink coloration; for example, near the backslope of the carse and near the base of the deposit where it rests upon gravel. The adjacent slopes partially veneered with till referred to as "clay and stones" in borehole logs, do not appear to contain the materials that would produce the colour change, ruling out slopewash as a possible explanation. However, an examination of the gravel beneath the grey silty sand provides another possibility.

In a number of boreholes that penetrate the grey silty sand, it is found that the uppermost layers of the underlying gravel contain a considerable proportion of pink sand or pink silty sand (Boreholes 445, 448, 452 and 455) that may well represent the re-deposition of material eroded from the High Buried Beach farther upstream. This mixture of pink sand and gravel is relatively unconsolidated in most cases, being reasonably penetrable until bigger gravel is reached, and it seems feasible to suggest that, at the time of deposition of the grey silty sand, a certain amount of mixing of grey and pink sediments took place. Later, as the grey deposit thickened, mixing was less.

Despite the limited area involved, the boreholes put down between Cambus and Alloa show typical buried beach sediments with their associated deposits. The presence of sub-carse peat or the buried valley of the Forth is to be expected after comparison with similar situations farther west, but the nature of the underlying gravel obviously merits further investigation. However, this is perhaps best covered below, along with the other areas of sand and gravel deposition. Here it seems more pertinent to attempt to fit the sediments into the buried beach sequence. The colour and composition of these sediments suggests that they may be equated with either the Main or Low Buried Beaches. Heights on the grey (silty) clay surface at 5.3 to 5.9 m O.D. correspond to heights on what has been described as the Low Beach between Abbey Craig and Menstrie and at East Gogar. Again, the grey clay at Cambus is very similar to that forming the Low Buried Beach near Thornhill. Despite obvious dangers in relating beach fragments over distances of as much as 20.0 km, the strong similarity between the structure of the Low Buried Beach in the west and the patch of beach deposits at Cambus suggests that they belong in the same category.

Other than the buried beach sediments, the main sub-carse deposit in the area between Stirling and Kincardine-on-Forth is sand and gravel. In a number of places, particularly near the eastern end of the area, till or even rockhead lies immediately beneath the carse-clay, but sand and gravel is by far the most common. In quantity the deposits compare with those of the Blairdrummond and Lecropt areas, but inspection shows a greater complexity in both form and distribution east of Stirling. For purposes of illustration and explanation, a division can be made between the sands and gravels that owe their morphology and distribution to fluvial deposition or erosion and those that have been effected by marine agencies. In a case such as this, where sea and river are so closely juxtaposed, no division can be absolute, but it would appear that there are areas in which one has been more important than the other. With this in mind, a line drawn across the region from north to south, near Alloa, separates an area of predominantly fluvial activity, to the west, from one of predominantly marine activity, to the east.

West of Alloa, the main source of sand and gravel is the River Devon along with the numerous streams flowing out of the Ochils. Each of these streams has its own alluvial fan as witnessed by the line of the carse edge from Airthrey in the west to Tillicoultry in the east where the carse itself merges with the fluvial deposits of the Devon. The biggest fans at Menstrie, Alva and Tillicoultry providing dry points above a wet plain have attracted the largest settlements, but almost every fan has its farm or small village. With settlement many of the streams producing the fans were artificially restricted to the one course to prevent flooding and for industrial purposes, but at times of heavy rain or melting snow in the Ochils, the streams occasionally burst their banks and spread sand and gravel over adjacent areas. Thus, the fans might be considered as still active, inasmuch as the streams have the ability to change the form of their surface, even if they do not significantly add to it. However, in the valleys behind the fans, there is gravel and sand that, under conditions of strong or high stream flow, could be carried downstream to be added to the fans and it is suggested that, without the curbs produced by settlement, they would continue to develop, if somewhat slowly and intermittently.

Although the fans are impressive features rising from the carse surface against the steep slope of the Ochils, these visible portions are, in fact, only sections of much larger features. At first sight, the fans appear to have built up on the carse surface, but this is only partly true, for while alluvial material does cover part of the carse-clay, the clay also masks the lower portions of the fans, which form an apron or piedmont of sand and gravel along the southern edge of the hills.

The relationship is well illustrated at Menstrie (Fig.V.7) where the more recent alluvium -- fine red-brown sand -- rests upon carse-clay and is often mixed with it. Away from the visible outer edge of the fan, the red-brown sand rests directly upon very coarse and tightly packed gravel. Followed in the opposite direction, towards the River Devon, these two deposits become separated by a bed of carse-clay. Between the carse and the coarse gravel, thin bands of other sediments are present, but this does not detract from the main point that a fan existed at Menstrie when the carse sea flooded into the Devon valley and continued to be built up after the deposition of the carse-clay. In addition, the mixing of sand and clay points to the probability that the two activities were at times contemporaneous.

In areas where no obvious fan exists it is still common to find gravel beneath the carse. Along the back of the carse near Powis Mains, for example, the clay often rests upon coarse brown sand or gravel (Boreholes 524, 525, 526, 530 and 531) and a similar situation has been found to exist west of Blairlogie. Where this is so, the source of the coarse material may well have been scree from the steep slopes behind the carse and in this regard it can be noted that screes are still to be found in places along the face of the Ochils. It is also possible that the conditions that led to the provision of abundant material for the fans were also conducive to the processes of mass-movement, allowing the accumulation of detritus that was later covered by carse-clay.

These two examples are repeated all along the face of the Ochils although the relationship between the clay and the gravel is best seen in the vicinity of the fans. On the Menstrie fan, thin bands of buried beach sediments are present between the carse-clay and the gravel. They have been interpreted as belonging to the High and Main Buried Beaches, the former being the older (Fig.V.7). At certain other points both hand auger and commercial boreholes have penetrated the High Beach and show that it rests upon sand and gravel (Boreholes 527, 528 and 529) providing evidence for a more accurate estimation of the relative ages of the fans and associated deposits. As well as pre-dating the carse, it can be seen that the fans were already in existence prior to the formation of the buried beaches in this area.

Near Alva a number of commercial boreholes show a stratigraphy that may be generalised as follows:-

5. Sandy clay or sand
4. Blue carse-clay
3. Sand and gravel
2. Clays and silts
1. Till

As at Menstrie, the sand and gravel shows the original development of the fan in pre-carse times while the upper sandy clay or sand indicates continued growth since. Furthermore, the difference in texture between the upper and lower deposits of the fan seems to indicate that, since the formation of the carse, the processes involved have been less vigorous and have therefore produced finer material.

The "clays and silts" that lie beneath the gravel are much more complex than this broad generalisation would suggest. In colour they vary from red to brown to grey and in consistency from "muddy silt" to "plastic clay". Considerable variations in thickness occur, but as much as 40.0 m of "clays and silts" have been recorded near Alva. In that same area, Parthasarathy and Blyth (1959) noting that they were laminated, generally free from large particles and contained arctic shells, considered these deposits to be of Late-glacial marine origin.

Near their base these clays often contain a considerable proportion of sand and are referred to as "red sandy silt" or simply "sandy clay". This may represent outwash sand poured into the sea by melting ice and in a number of boreholes the clays are separated from the basal till by sand or gravel indicating fluvioglacial activity during the retreat of the ice. Further complications are added in a few cases, by the presence of two layers of till separated by a bed of sand or gravel. It seems possible that this indicates fluctuation of the retreating ice, but the paucity of information limits the amount of interpretation that can be made.

One point that emerges from an investigation of these boreholes concerns the formation of the Ochil fans. It has been established above that they existed prior to the formation of both the carse and the High Buried Beach, while evidence from the deep boreholes shows that they were growing soon after, or perhaps during the deposition of the Lateglacial clays, for the presence of sand or fine gravel beds mixed with mud and clay immediately below the main gravel may represent a mixing of the two deposits. Thus, it is evident that the Ochil fans are considerably older than is at first apparent.

It seems likely that the bulk of the gravel in the area west of Alloa was deposited by the Ochil streams and the River Devon. As well as providing its own material the latter may have helped to re-distribute sands and gravels by the erosion of the southern edges of some of the fans. At Menstrie, for example, the fan is limited by a buried valley of the Devon on its southern edge and the configuration of the deposit suggests that it may have suffered erosion by the river. Upstream from Menstrie, recognition of the buried valley is difficult but it may be represented by the absence of gravel from its normal position in the stratigraphy. Near the present river, a few boreholes show that gravel may be completely lacking or present only at some depth mixed with muddy sands and clays, showing the complicated sedimentation that might be expected with the flooding of such a valley.

West of Menstrie, the present Devon turns sharply southwards towards the Forth. Near East Gogar the carse adjacent to the river rests upon a gravel surface heighted at between 4.0 and 5.0 m O.D. Followed westwards, the gravel retains its relatively level surface for almost half a kilometre before dying out. Beyond that point the stratigraphy consists of muds and clays down to an altitude of -1.3 m O.D. where rockhead is encountered (Fig.V.8). Adjacent boreholes show that gravel is absent, or present only at depth, and it is suggested that the edge of the gravel surface at East Gogar marks the eastern margin of the buried valley of the Devon. The position of the western edge of the valley is not evident from the information available. However, it would seem that at some time after the deposition of the main mass of gravel the Devon followed a course that carried it farther west than at present. It must be stressed that this valley bears no relationship to that examined by Soons (1960) in the same area. The latter consisted, basically, of three glacially deepened rock basins near Menstrie, Alva and Tillicoultry, that did not bend round to meet the Forth. In contrast, the valley described here, does approach the Forth, is fluvial in origin and is obviously a much younger feature.

Although the major source of sand and gravel for this area is seen as the Devon valley and the Ochils, in the southern section, near the Forth, a possible origin is to be found west of Stirling. It would seem reasonable to suggest that the Stirling gap acted as an exit for sand and gravel from that area, if not in the form of outwash at least as material eroded from the deposits at Lecropt and Blairdrummond. It is not possible to distinguish between gravel from different sources, east or west of Stirling, but it is to be expected that material from the latter area would be found in bore-holes adjacent to the present course of the Forth.

An examination of the heights at which the surface of the buried gravel is encountered near the Forth, shows a considerable variation from +2.1 m O.D. to -8.1 m O.D. However, a majority of values are grouped around O.D. At Ladysneuk, for example, close to Abbey Craig, the gravel surface is at -0.2 m O.D. while one kilometre farther east, at Manorneuk, heights between +0.4 and -0.1 m O.D. appear to be representative and farther east again, near the confluence of the Devon and the Forth, corresponding values are +0.2 and -1.0 m O.D. Although the boreholes, in which gravel is found at such heights, number only 20, they are clustered into a number of patches separated by areas where gravel is absent, or present only at some depth, and it is thought that they may be the remnants of a surface that once covered a larger area, with subsequent erosion by both the Forth and Devon producing the present distribution.

Between Cambus and Alloa, this gravel is no longer present at or around O.D., but a similar deposit forms a step beneath the landward part of the carse (Fig.V.6). This latter feature is not directly related to the former, for its surface lies at heights between 4.0 and 5.0 m O.D. forming a distinct ledge at least one kilometre long and as much as 250.0 m wide, with a cover of peat and buried beach sediments up to 2.0 m thick. In height, this ledge is very similar to the gravel surface near East Gogar, although separated from it by an area west of Cambus, where mixed clays and sands overlie rock at 3.0, 5.3 and 10.6 m O.D., gravel being absent. However, in both areas, a number of boreholes indicate that the upper few centimetres of the gravel contain a proportion of pink sand or pink silty sand. This condition has been examined at Cambus and its presence in an adjacent area suggests formation under similar conditions. Noting the similarities in height and composition it is considered that the gravel surfaces at East Gogar and Cambus represent separate parts of the same feature.

Followed eastwards the Cambus gravel is lost beneath the built-up area around Alloa. The limited number of boreholes within the town give no indication of its presence and to the east there is no re-appearance of a similar feature. Gravel is still very much part of the stratigraphy, but is does not take the same form as that to the west. Instead of having the characteristics of a sharply defined, relatively flat-topped terrace as at Cambus or East Gogar, it forms part of a sloping surface that varies in height from as low as -5.9 m O.D. near the Forth to as high as +5.0 m O.D. near the back of the carse. Furthermore, the gravel is not continuous, but interrupted by areas of till and rock that lie at heights comparable to those on the surface of the gravel. Thus, the surface is in fact a composite one, comprising areas of gravel, till and bedrock, the whole feature sloping from the inner edge of the carselands towards the present river.

The surface is almost continuous between Alloa and Kincardine, but is modified slightly near Kennetpans where an embayment occurs and the stratigraphy includes no gravel, only clays of silty sands resting upon rockhead at -10.1 m O.D. Near Kincardine, the feature is well developed in gravel, till and rock (Fig.V.9) while in the vicinity of Clackmannan, rock with small amounts of gravel, is the main component (Fig.V.10). Throughout the area the gravel varies in thickness from 0.2 m to a maximum of 8.7 m but in most boreholes it is little more than a metre thick. In addition there is no well marked pattern as far as the distribution of these figures is concerned, adjacent boreholes showing variations of as much as a metre, but in general, the gravel appears to thin out towards the inner edge of the feature and may be completely absent at the back where its place is taken by rock or till. This pattern is broken near Kilbagie where sample gravel thicknesses at the back of the feature are 2.1, 2.7 and 3.0 m while to the south of this in the Kincardine area, figures of less than one metre are common and minima of 0.2 and 0.3 m have been recorded. Apart from this the original generalization appears to hold true.

A feature, similar in terms of height, form and composition, to that described above, has been reported in an area between Grangemouth and Airth on the south side of the Forth (Sissons, 1966, 1969). Although the northern portion is somewhat smaller than that to the south, both have a number of characteristics in common. The height range encountered in both cases is between +6.0 and -6.0 m O.D. with only occasional values outside this and most clustered around O.D. As well as height range, height distribution is also similar, so that each feature rises from its lowest points near the present River Forth to its highest beneath the northern or southern limits of the carselands, as the case may be. Turning to the composition of the surface, the comparison can be followed through, with the gravel layer, planated rock and planated till present on both sides in similar situations. On the southern side of the Forth, however, the gravel appears to be more extensive. The gravel may rest upon each of the other elements making up the surface, but more commonly it overlies deposits referred to in the borehole logs as red, brownish-red or brown clay and interpreted as Lateglacial marine clays. Taking this evidence into consideration, it seems certain that both surfaces were formed contemporaneously and under the same conditions.

Sissons has interpreted the gravel layer as representative of a period of marine erosion during which rock and till were planated while the gravel layer itself was built up from material eroded from the till and other superficial deposits along the shoreline (Chapter I). A marine formation was supported by a number of factors including the form of the feature, the presence of planated rock and till, the truncation of the underlying Lateglacial clays, the incorporation of shells in the gravel layer and the existence of marine cliff-forms at a number of places along the landward margin of the surface. The first three pieces of evidence also apply to the feature on the northern side of the Forth. However, neither shelly gravel or cliff-forms are common. Near Clackmannan, shell fragments have been found resting upon planated rock, but it is possible that they are associated with the carse sea rather than with an earlier sea-level. In the case of the cliffs, two factors might explain their absence. The main cliffs on the south side of the Forth are cut into the sediments of the raised beaches associated with the Perth Readvance. In contrast, similar sediments are not present along the inner margin of the buried gravel layer to the north, for the latter lies mainly within the limits of the readvance (Sissons and Smith, 1965a) and for the most part the gravel merely thins out against the rising rock surface. Where the cliff has been cut in solid rock as it has south of Hill of Airth, Sissons sees ice accomplishing the original erosion of the rock with marine activity later producing some modification. Along the north shore, glacial action can be seen in the moulded form of the landscape along the back of the carse but the sea that produced the buried gravel layer does not appear to have taken advantage of any steepening of the shore. At most the sea appears to have eroded till veneering the glaciated surface, incorporating the constituents in the gravel layer.

Looking at the general configuration of the landscape around Kincardine, Grangemouth and Falkirk where the main development of the gravel layer occurs, it can be seen that the greatest exposure is to the east and north-east out over the waters of the widening Firth of Forth. An increased frequency of easterly or north-easterly winds at some time in the past may well have been instrumental in producing the erosion associated with the formation of the buried gravel layer. In such a situation, the relatively sheltered nature of the shoreline between Kincardine and Alloa would have limited cliff development and restricted the extent of the gravel on the northern side of the Forth.

In the Grangemouth-Falkirk-Airth area, Sissons (1969) was able to deduce the age of the buried gravel from its relationship to adjacent sediments. It could be shown to be younger than the Perth Readvance since it extended into the area covered by ice at that time and since its formation was accompanied by erosion of deposits associated with the readvance. Both facts apply north of the Forth also, but without the cliffing of the Perth Beach sediments in the second case. The other event used by Sissons to establish the age of the gravel was the formation of the Main and Low Buried Beaches, both of which overlie the gravel layer in parts of the area. Using this information it could be shown that the buried gravel came into being some time after the Perth Readvance but prior to the formation of the buried beaches. On the northern side of the Forth, the latter are not conspicuous and appear to be present only as isolated patches of fine grey sand, that do rest upon the gravel where they are encountered. Thus it is assumed that the bracketing dates established for the gravel south of the Forth also apply north of the river.

Followed westwards beyond Alloa it is suggested that the gravel layer may be equated with the patches of gravel lying close to the present course of the Forth as far west as Stirling. With altitudes close to O.D. corresponding to heights on the buried gravel in the Kincardine area, it is thought that they indicate its westward extension up the Forth valley. The gravel surfaces at East Gogar and Cambus also compare in terms of height with the higher parts of the buried surface farther east. However, at neither of these places in the west does there appear to be a direct link between the higher and lower gravels. It is considered that the surfaces at East Gogar and Cambus, although perhaps not unaffected by the presence of the gravel sea, are essentially depositional in origin, the constituent materials being provided by the Forth and the Devon as well as certain local streams.

Finally it should be noted that close to the Forth boreholes often show a stratigraphy that is rather complicated and inexplicable in terms of the features indicated above. The same is true of the Devon where a hand bore was put down for over 8.0 m through soft layers of clay, silt and sand without encountering buried beach or buried gravel deposits. It is thought that this indicates the presence of buried valleys beneath the main rivers, similar to those discovered west of Stirling.

Conclusion

In the area between Stirling and Kincardine the sub-carse deposits are notable for their variety and complexity. The following elements have been identified.

1. The High Buried Raised Beach, lying beneath the northernmost part of the carselands between Abbey Craig and Menstrie. In this area, the beach is composed of pink silty sand and clay with a layer of soft peat normally covering its surface. Heights along the former shoreline vary between 10.7 and 7.9 m O.D. while along the southern edge of the feature values as low as 7.3 m O.D. have been recorded.
2. The Main Buried Raised Beach, resting upon the eroded southern edge of the High Beach. Grey silty sand is the main constituent of the beach which supports a thin and variable cover of peat. Heights on the surface of this feature fall within the range 6.6-7.7 m O.D.
3. The Low Buried Raised Beach, present along the edge of the Main Beach and in a very limited area near Cambus. In both places it is composed of grey (silty) clay resting upon grey silty sand, but at Cambus the clay cover is thicker and more uniform. Measurements on the surface of the feature show that it varies in altitude between 5.7 and 6.8 m O.D. south of the Main Beach and between 4.5 and 5.9 m O.D. at Cambus. As in the case of the other beaches, the Low Beach is overlain by a bed of peat.
4. The alluvial fans built up along the southern edge of the Ochils. Some of the sediments forming these features rest upon the carse, but the bulk of the sediments can be followed beneath it and also

beneath the buried beach sediments indicating the relative ages of these features. The streams forming the fans, in combination with the Forth and Devon appear to have been mainly responsible for the widespread distribution of gravel in this area, from Alloa westwards.

5. The Buried gravel layer and accompanying planated till and rock. This feature is best developed between Alloa and Kincardine with a possible westward extension almost as far as Stirling. Its surface slopes with varying steepness from its back edge towards the Forth, producing a height range of +5.0 to -6.0 m O.D.
6. The buried valleys of the Forth and Devon. Although not nearly so well developed as those farther west, they form significant elements of the sub-carse morphology in certain areas. The valley of the Devon joins that of the Forth a short distance west of the confluence of the present streams.

CHAPTER VI

RESULTS OF THE LABORATORY ANALYSIS OF SELECTED SAMPLES

As noted in Chapter II, sediment samples were collected at various localities between the Lake of Menteith and Kincardine-on-Forth and subjected to laboratory analysis. Initially, 93 samples were examined, allowing a sample/borehole ratio of 1 to 7. Of these samples, 72, comprising both carse and sub-carse deposits as well as gravels and recent fluvial sediments were selected for additional analysis. Buried peat was also collected for special examination.

Due to the empirical method of selection, the sample sites were not uniformly distributed throughout the area and this had certain repercussions in terms of the proportions of the various sediments in the total sample. As a result of this and partly due to the overall distribution of the various sub-carse deposits, the number of samples of each sediment type was not the same. Being the most widely distributed, grey silty sand accounted for the largest proportion of the samples with a total of 22, while the remainder were almost equally divided between carse-clay, pink silty sand, grey silty clay and the other sediments noted above. Finally, certain limitations were imposed by the shallow sampling of the buried beach sediments, the small sample size and the possible contamination of the samples. These problems have been outlined in

Chapter II and can be considered to apply to all sub-carse deposits.

As a beginning, three methods of analysis were considered useful for the present investigation. Firstly, measurements of the hydrogen ion concentration or pH of the deposits were taken in an attempt to obtain some insight into their formation. This relatively simple method of showing the degree of acidity or alkalinity of sediments was chosen as a means of examining their supposed marine origin, on the premise that, in the area concerned, marine deposits should produce readings tending more towards the alkaline end of the scale than fluvial or other deposits.

Secondly, mechanical analysis was carried out on the samples to determine the proportions of sand, silt and clay in each. From field inspection, it had been noted that the various sub-carse deposits were normally distinguishable by their texture, and mechanical analysis was in part a means of quantifying this. In addition, it was considered that the results could be used in conjunction with the stratigraphy and distribution of the sediments to give some information on their origin.

Thirdly, each sample was to be analysed for organic carbon content. The carse-clay often contains organic material distributed in lenses or fragments throughout its thickness. Compared with this, the sub-carse deposits with few exceptions are not obviously organic, but to examine the possibility of fine organic material being well mixed with the deposits, a number of samples were chosen for pilot experiments. From 24 tests carried out using an EEL colorimeter to estimate the percentage of carbon present (Chapter II) only 7 showed values greater than 1%, the highest being 2.4%. For the tests a representative cross-section of samples was used, including sub-carse sediments, carse-clay and recent river alluvium, but the final results produced no obvious pattern apart from generally low values throughout. Even the carse-clay proved low in organic carbon although vegetable matter and shell fragments are often associated with it. However, it is thought that this anomaly may be explained by the organic material being concentrated in lenses or bands rather than distributed throughout the clay.

Sub-carse deposits accounted for 5 of the 7 samples with more than 1% carbon but a further 10 were well below this figure and it was considered that the higher values were not representative of the deposits as a whole but, due to contamination of the sediments by the buried peat layer or due to rootlets from this layer passing down into the sub-carse deposits. As a result of these preliminary tests, it was considered that the amount of organic material in the buried beach sediments was too low to merit further investigation. Therefore no additional tests of this type were carried out, this decision also being influenced by the difficulty of ensuring uncontaminated samples.

Thus, laboratory work on the sediments consisted mainly of the determination of pH and mechanical analysis. In addition, an attempt was made to examine the buried peat layer for pollen content in a few localities, while the end-products of mechanical analysis were treated for heavy mineral determination. In the following paragraphs, the results of these experiments will be presented and explained.

Determination of pH.

The samples used in this experiment fell into four broad groups. These consisted of the three different sediment types associated with the High, Main and Low Buried Raised Beaches together with the carse-clay. In general the average pH values in each group show them to be moderately or only slightly acid with individual samples ranging from strongly acid to weakly alkaline.

The highest value was produced by the pink silty sand of the High Buried Beach with no individual result below a pH of 5.8 and an overall mean of 6.6 indicating very slight acidity. Closest to this among the sub-carse sediments was the grey silty sand with an average pH of 6.2, concealing a range of values between 4.7 and 7.4. In this case, the three lowest results were found in sediments obtained from beneath Flanders Moss, but, apart from this, there is no obvious pattern to the distribution of the pH values. The most acid of the deposits proved to be the grey silty clay of the Low Beach, giving a spread of results between 4.5 and 6.8 with a mean of 5.6. In addition pH measurement of the carse-clay samples gave indications of slight acidity overall with a mean of 6.3 and a relatively small range between 5.1 and 7.2. The above, and other relevant information on pH determination, is brought together in Table VI.I.

Although these experiments are relatively simple and provide results that are to some extent to be expected, they do require some discussion or explanation. It has been recognised for some time that the carse-clay is of marine origin (Chapter I) and the work of Sissons (1966) and Newey (1966) has indicated a similar formation for the sub-carse deposits examined here. Since the salinity of sea-water produces a high pH of the order of 7.5 to 8.0 (Strickland and Parsons, 1968) it might be expected that sediments laid down in a

TABLE VI.I

Measurement of pH

	Number of Samples	Maximum pH	Minimum pH	Mean
High Buried Beach	8	7.4	5.8	6.6
Main Buried Beach	26	7.4	4.7	6.2
Low Buried Beach	10	6.8	4.5	5.6
Carse-clay	12	7.2	5.1	6.3

N.B. The carse-clay samples were collected at depths greater than 1.0 m, to escape the effects of agricultural activity.

marine environment would show values similar or close to this. Some of the results quoted here approach the lower end of this scale but the majority show at least slight acidity. However, several points can be put forward in explanation of this.

In the first place, it is considered that during the formation of the buried beaches, and the carse, sedimentation was taking place in a modified marine environment. The introduction of fresh water at the head of the Forth estuary would have the effect of reducing the salinity and the pH of the water, the latter being aided by the fact that the fresh water originated mainly on the relatively acid rocks of the Highlands. In the case of the High Buried Beach, formed according to Sissons (1966) when ice was present and melting in the upper Forth valley, large quantities of fresh water must have been present, yet for some reason it has produced the highest average pH of any of the beaches. It would seem likely that even when the buried beach and carse sediments were first laid down, their pH values were lower than normal in marine deposits due to their estuarine location.

Once the sediments had been deposited they were exposed and vegetation grew over their surface as indicated by the buried peat layer in the case of the buried beaches. Holmes (1966) notes that the pH of moss peat may be as low as 2.8 to 3.7 and, in the present study, measurements made on a lense of peat enclosed in carse-clay gave values of 2.5 and 2.6. As the peat grew, percolation of acidulated water into the underlying sediments would have the effect of increasing their acidity. The leaching of salts from the upper layers of the exposed deposits would have similar results. Again the deposits of the High Beach are anomalous in that they show what appears to be strong physical evidence of leaching in the grey surface layer, yet the pH values remain comparatively high. Compared with this, low results in other deposits may represent leaching. Parthasarathy (1954) saw leaching as responsible for certain low salinity readings in the Devon valley carse-clay and this may be reflected in other areas in low pH values. Five samples taken from within a metre of the carse surface gave results ranging from pH 3.8 to 4.5 while samples from greater depths normally gave pH values greater than 5.0. The carse, however, unlike the buried sediments, has undergone agricultural interference of various forms and this has undoubtedly affected it chemically, especially in the surface layers.

Taking the above factors into account, it is perhaps somewhat surprising that the pH values have remained as high as they have. It is suggested that they are still sufficiently high to indicate a possible marine origin for the buried beach deposits. Although not sufficiently strong in themselves to prove such an origin, the pH experimental results add to the pollen and topographical evidence (Newey, 1966; Sissons, 1966) and provide at least some contribution towards the conclusive proof of a marine origin for the sub-carse sediments.

Particle Size Analysis.

The results of particle size analysis carried out on the buried beach and carse sediments (Fig.VI.1) are based on a total of 72 samples examined using a combination of hydrometer analysis and sieving techniques (Chapter II). During the collection of the

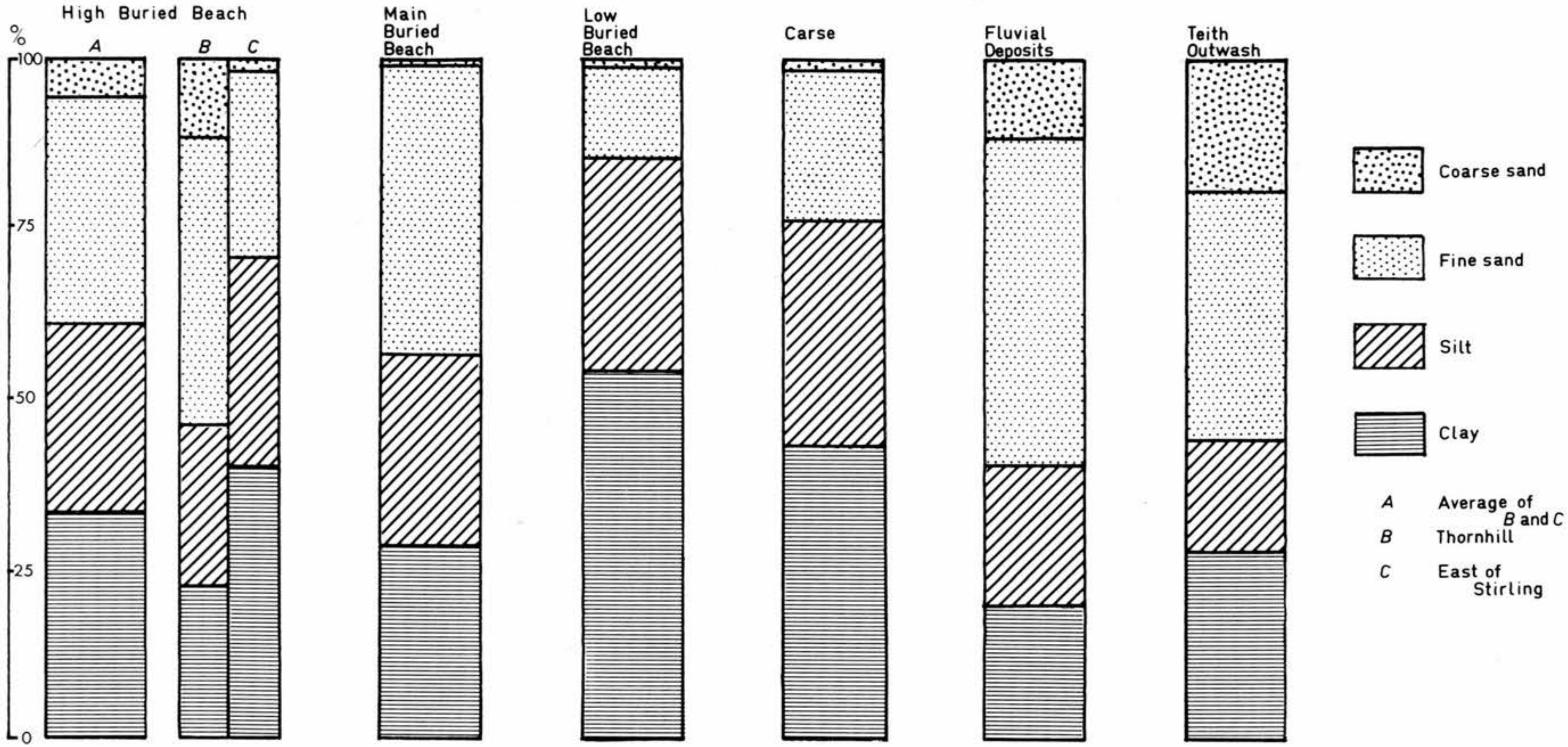


Figure VI.1 Average composition of buried beach and associated deposits samples, and during preparation for analysis, it became increasingly obvious that very fine deposits were being dealt with. For example, it is normal to sieve air-dried samples initially through a 2.0 mm mesh, retaining the sub-2.0 mm fraction for mechanical or chemical analysis and discarding the remainder after weighing. With both buried beach sediments and carse-clay, no sample was found to contain measurable quantities of material larger than 2.0 mm in diameter. According to the size scale used (Table VI.II) this meant that in none of the deposits were there particles present with equivalent diameters greater than those found in coarse sand and in fact only a few samples contained a proportion of that fraction.

TABLE VI.II

Equivalent Particle Size Diameter (in millimetres)

	2.0-0.2 :	0.2-0.02 :	0.02-0.002 :	Below 0.002
Fraction:	Coarse sand	Fine sand	Silt	Clay

(After Russell, 1966)

The deposits of the High Buried Beach were analysed for particle size at eight locations, three of which lay in the vicinity of the village of Thornhill and five close to the Ochil Hills, east of Stirling. The results of analysis gave the proportions of the various size fractions at each location and from this the average composition was calculated. Following the scale outlined in Table VI.II, this showed that the deposits of the High Beach contain on average, 5.5% of coarse sand, 33.0% of fine sand, 27.9% of silt and 33.6% of clay.

Despite the limited sample size, certain overall characteristics, as well as individual variations, could be seen. In his work on the south side of the Forth, Sissons (1967a) has referred to the sediments of the High Buried Beach as "pinkish silty sand" and the same term has been used in the present study. On consideration of the average figures, it can be seen that the sand and silt fractions together account for 66.4% of the total, apparently confirming the use of the term "silty sand". However, a combination of the silt and clay percentages gives a figure of 61.5% suggesting that, in some cases the deposits are as much "silty clay" as "silty sand". Further illustration of this can be seen in the mean composition of the Thornhill and Stirling groups. In the former, the sands and silt provide 77.5% of the total compared with the 46.0% of the silt-clay combination, while east of Stirling sands and silt together make up only 59.8% of the whole, silt and clay accounting for 70.8%. Thus in the western part of the area under study, the High Buried Beach is composed of measurably coarser material than the corresponding feature in the east.

The limited number of samples examined from the High Beach deposits restricts the conclusions that can be made. However, when viewed in conjunction with field observation there is a degree of correlation between the visual evidence of texture and the laboratory results. It was noted above that the sediments of the High Buried Beach between the Lake of Menteith and Blairdrummond appeared relatively coarse when examined initially in the field (Chapter III) and this is confirmed in the mechanical analysis figure of 11.7% for the coarse sand fraction. In contrast, east of Stirling, the deposits have a higher clay content (Chapter V) as is evident from the percentage of that fraction revealed by laboratory analysis. In this latter case, the results are probably somewhat misleading, for there are areas in the High Beach along the edge of the Ochil Hills where the deposit is visibly coarse. Overall, the distinction between the two areas may be related to the environment in which sedimentation took place and this will be pursued further, below (Chapter VII).

In the same way, mechanical analysis tests were carried out on 20 samples collected from the deposits of the Main Buried Raised Beach. An average for all 20 samples was calculated and this gave values of 0.5% coarse sand, 43.3% fine sand, 27.7% silt and 28.5% clay, which would appear to be in agreement with the term "silty sand" commonly used for the Main Beach sediments. In some cases the term "fine sand" has been used for descriptive purposes and this is reflected in the relatively high figure for fine sand obtained from analysis. Indeed, the average masks some very high individual values in the fine sand fraction, nine of which exceed 50.0% with an absolute high of 65.3%.

The typically fine texture of the deposit is also indicated by the small percentage of coarse sand encountered. Only eight samples contained that fraction at all and then only in very limited quantities. With only one exception the coarser material was limited to samples collected west of Stirling and on closer inspection a definite pattern could be seen. Five of the samples were collected close to the junction of the Main Beach and the Teith sands and gravels while one of the others was sufficiently close to the buried valley of the Goodie Water to have obtained coarser sediments from that source.

Elsewhere, both east and west, coarse sand is atypical of the deposit as a whole.

The mechanical composition of the third of the buried features, the Low Beach, was examined in ten samples. The deposits of this feature are easily recognized in the field as being rather finer in texture than those of the higher features and this is borne out in the analysis. Some problems arose during the experimental work apparently because of the fine nature of the Low Beach sediments. It was found that the hydrometer floated at very high levels in the suspension, perhaps due to the slow rate of fall of the fine clay particles. As a result, the cumulative percentage, from which the final composition was measured (Chapter II), did not correspond to the results obtained by sieving. In a number of experiments, the highest cumulative percentage measured by hydrometer analysis proved to be 10-20% higher than the lowest percentage obtained by sieving (whereas the former should have been the lower of the two), the exact difference depending upon the diameter of the sediment particles involved at each stage. The exact cause of this disparity could not be determined, but experiments showed that, especially with the finer sediments, an original trial sample of greater than 30.0 gms in weight reduced the possibility of the above occurrence.

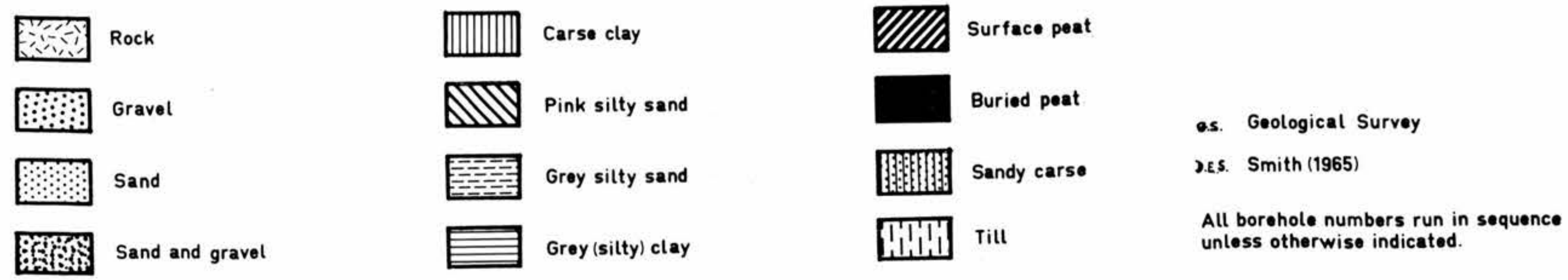
Analysis of the deposits of the Low Buried Raised Beach showed that on average they contained 1.0% coarse sand, 13.7% fine sand, 31.2% silt and 54.1% clay. Despite the presence of the coarse sand, with a value greater than that for supposedly coarser Main Buried Beach, the most obvious factor is the high percentages of silt and clay. Together they comprise over 85% of the total. As with all average figures the extremes are lost and in this case the latter are perhaps more interesting than the former. Of the ten samples examined, three gave silt-clay combinations greater than 90% with a maximum of 98% in two of these three. Only two of the remainder fell below 80% and in one sample, the proportion of clay alone stood at 81%. Despite the limited number of samples used the extremely fine texture of the deposits of the Low Beach is rather obvious and characteristic of the feature.

Having considered each of the buried beaches in turn, in terms of their mechanical composition, they can now be compared both in terms of average results and also in terms of results from individual samples. To facilitate this, each sample was plotted on triangular graph paper in terms of its clay, silt and sand content. Where a sample contained both fine and coarse sand fractions, these were taken together for representation on the graphs. The final results are presented in Figure VI.2.

In the first place the values obtained for average composition were plotted and these show the general location of each group with a broad indication of the relationship between them. The most obvious features of this graph (Fig.VI.2a) are the close proximity of the High and Main Buried Beach deposits and their separation from the average plot for the Low Beach samples. It can be seen that the main differences lie in the sand and clay fractions. All three are similar in terms of their silt content, but the Main and High Buried Beaches have approximately 20% more sand than the Low Beach while in the latter the difference is made up by a similar percentage increase in the clay fraction.

THE SUPERFICIAL DEPOSITS OF THE AREA BETWEEN—
——— STIRLING AND KINCARDINE-ON-FORTH

(The location of each section is indicated in Figure V.1.)



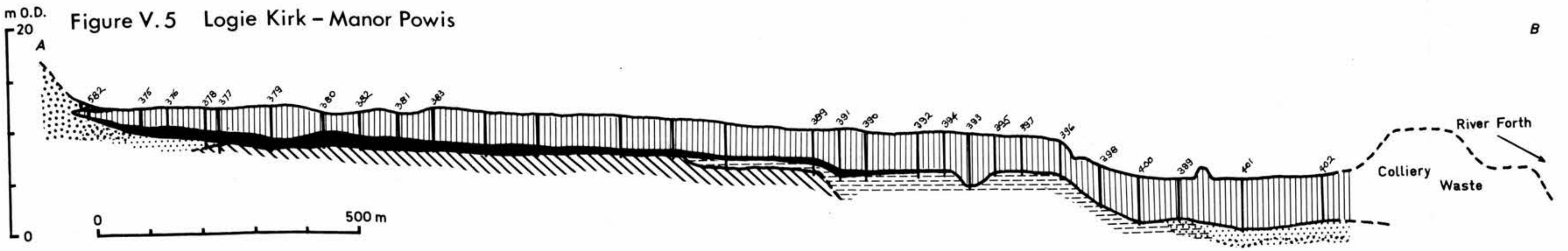


Figure V.5 Logie Kirk – Manor Powis

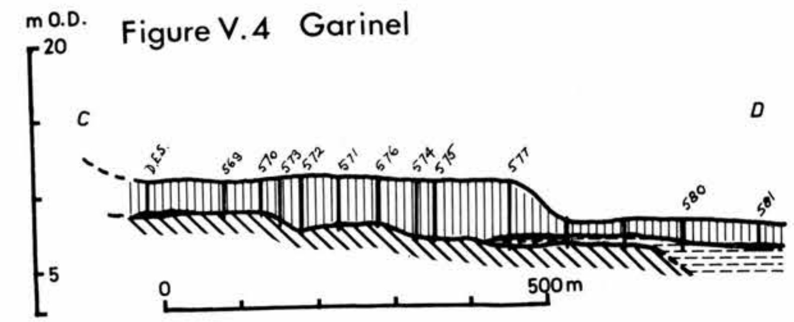


Figure V.4 Garinel

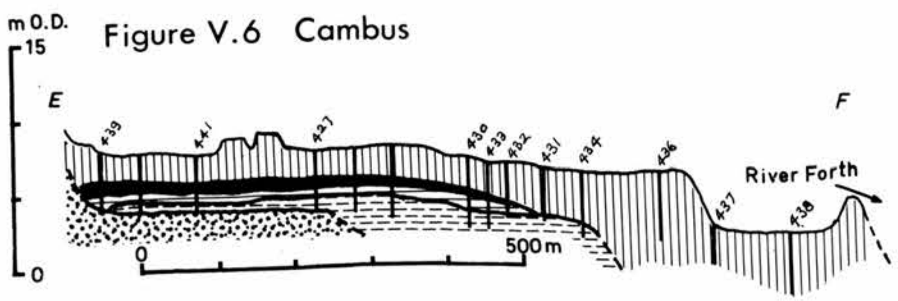


Figure V.6 Cambus

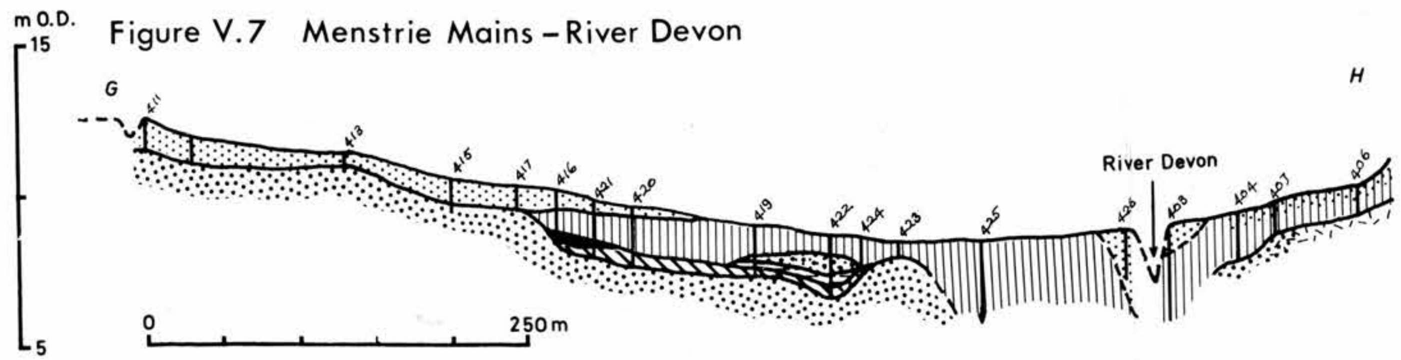
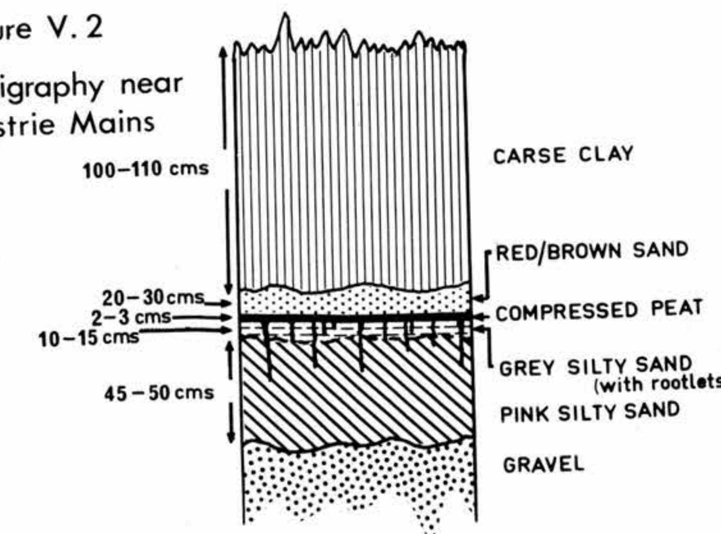


Figure V.7 Menstrie Mains – River Devon

Figure V.2

Stratigraphy near Menstrie Mains



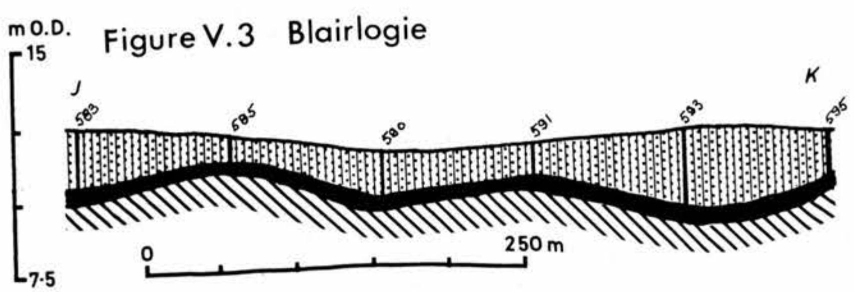


Figure V.3 Blairlogie

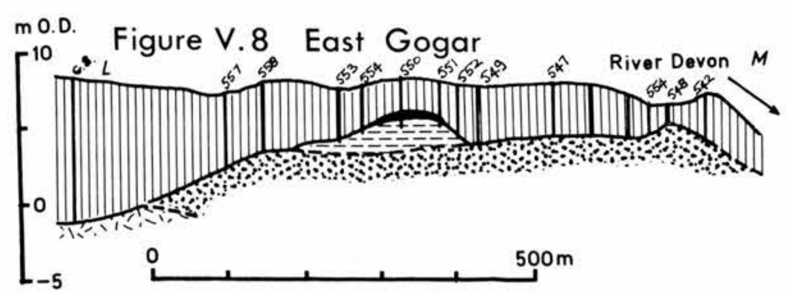


Figure V.8 East Gogar

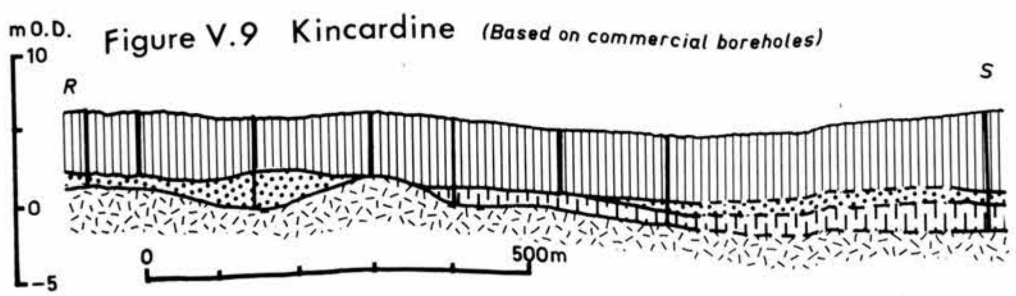


Figure V.9 Kincardine (Based on commercial boreholes)

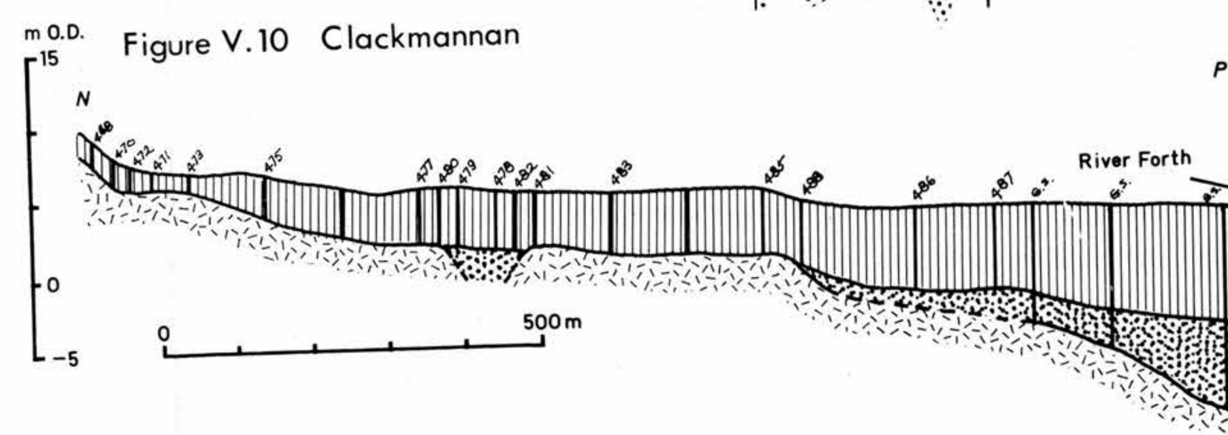
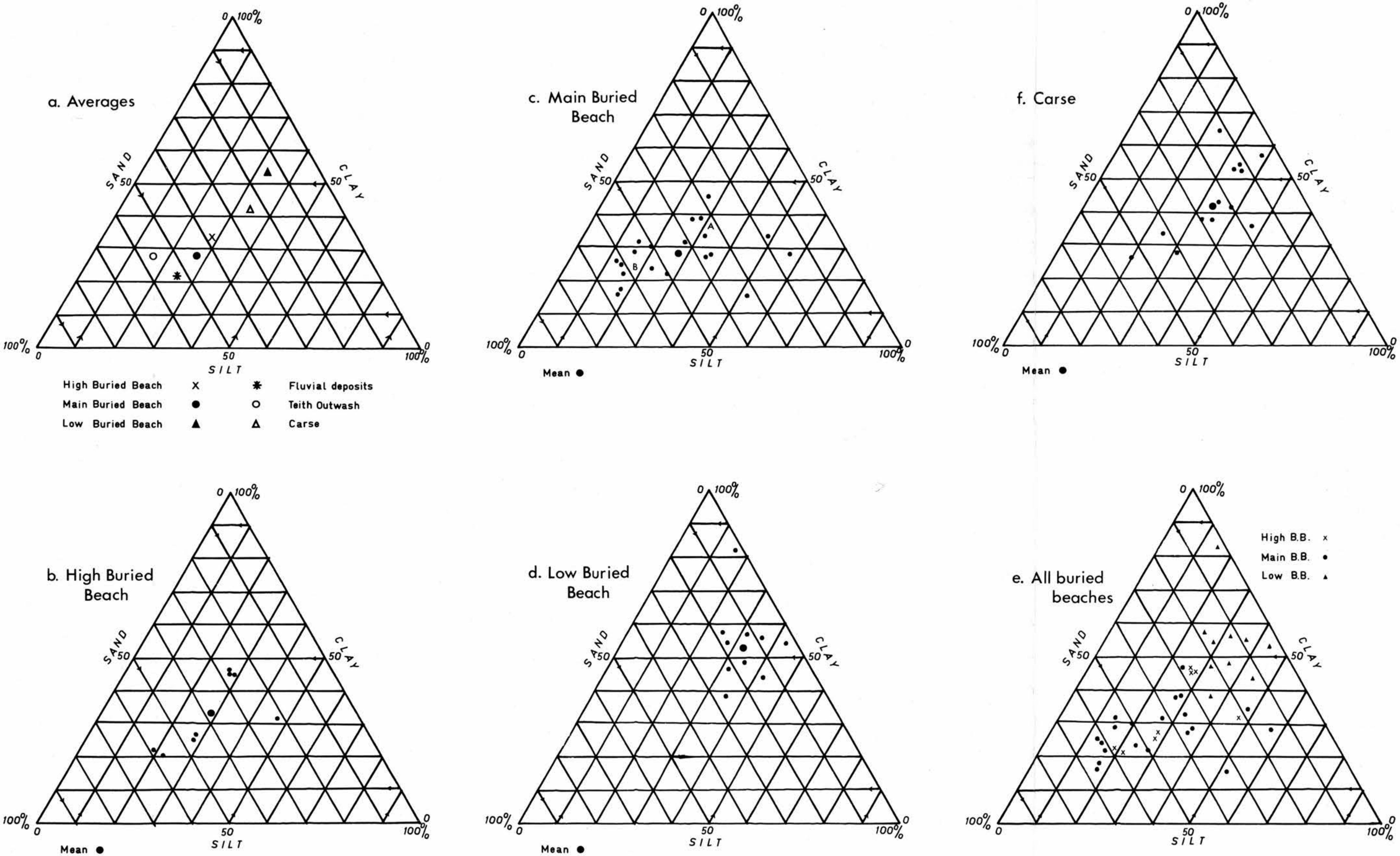


Figure V.10 Clackmannan

Figure VI.2 Results of particle size analysis



For comparison, the mean composition of a number of deposits associated with the buried beaches has been calculated and plotted on the graph. These include carse-clay (13 samples), recent deposits of the River Forth or Teith (6 samples) and the finer sediments of the buried outwash fan at Blairdrummond (5 samples). As can be seen, the carse-clay is more akin to the deposits of the Low Buried Beach than to the others, a fact that was often apparent in the field, where the main difference between the two often appeared to be one of colour alone. However, in certain areas, the mixing of carse-clay with coarser fluvial deposits produced the variety already noted (Chapters III, IV and V). With both the river sediments and those of the buried fan, the average plot shows a composition somewhat coarser than any of the buried beaches.

All points mentioned thus far refer only to average conditions and closer examination shows considerable variation from the mean in a number of cases.

Despite the limited number of samples of High Beach material, the graph (Fig.VI.2b) does indicate a division into two groups dependent upon differences in the clay and sand fractions, the silt content being similar in both cases. On examination of the location of the samples involved, it was found that the groups were mainly a graphical indication of the textural differences in the beach between Thornhill and the area east of Stirling.

On the graph showing the composition of the Main Buried Beach (Fig.VI.2c) a division into two main groups can be made also, although the distinction is not so clear as with the High Beach. One set of points (A) indicates a rough balance between sand, silt and clay, while in the other (B) the sand shows a definite increase at the expense of the silt. Unlike the High Beach there is no obvious relationship between location in the field and position in one or other of the groups. However, if a distinction is made between coarse and fine sand, deposits with a proportion of the former are commonly linked with the area west of Stirling. This brings out one of the drawbacks of the system of graphical representation in which coarse and fine sand are taken together. Considering Figures VI.2b and VI.2c it can be seen that five of the Main Beach samples have greater proportions of sand than the sandiest of the High Beach samples suggesting that the former is the coarser of the two. Nonetheless, a breakdown into coarse and fine fractions shows that in absolute terms the High Buried Beach, with its 5.5% of coarse sand, is the coarser.

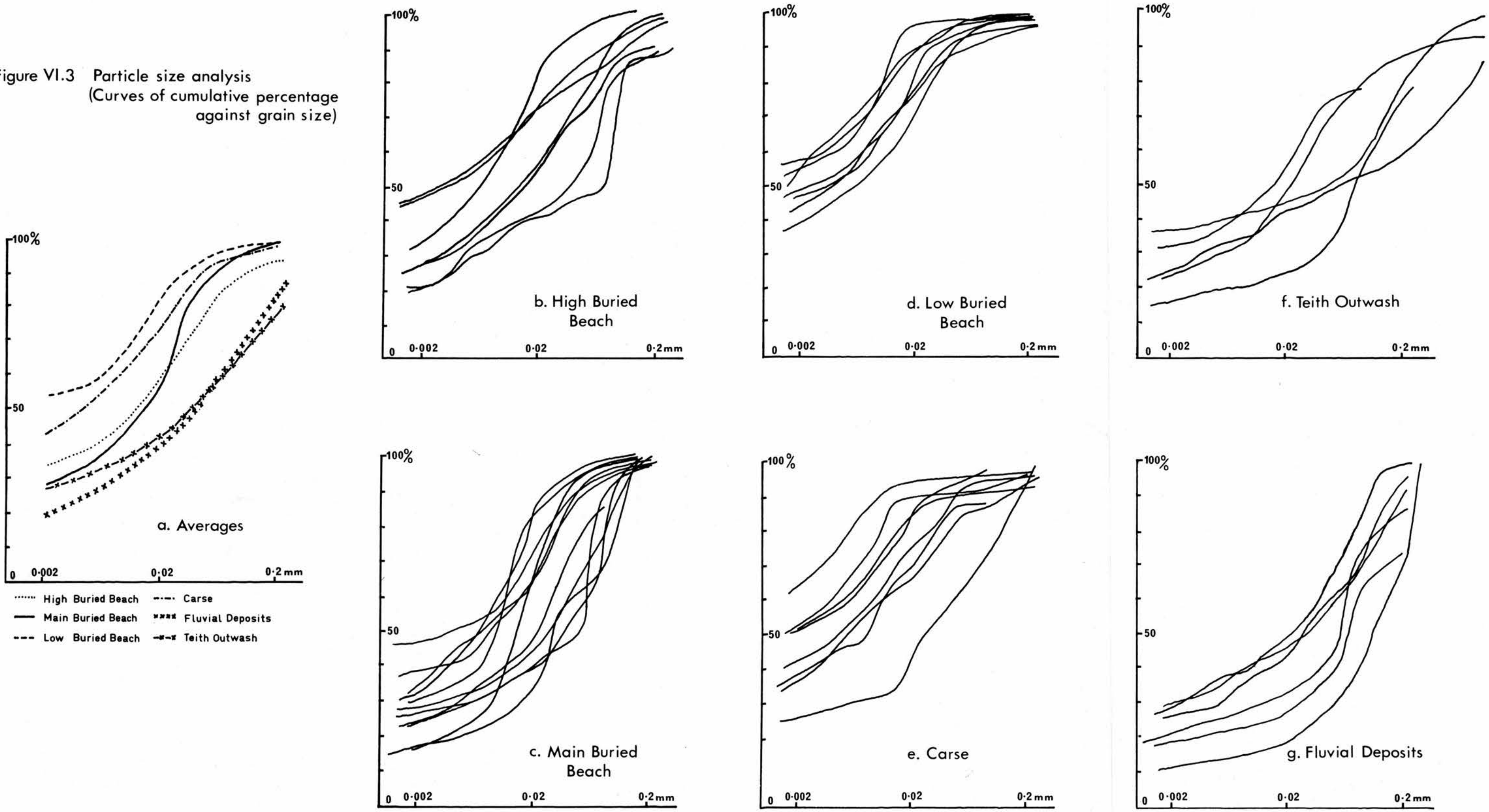
The fine nature of the deposits of the Low Buried Raised Beach is apparent in Figure VI.2d. Nine of the ten samples examined contain more than 40% clay and all but one lie within the range 40-60% clay. That which shows 81% clay is well separated from the remainder which form a distinct grouping. The sediments of the Low Buried Beach tend to be more homogeneous than those of the other beaches as may be seen when all are plotted graphically. With only ten samples chosen, it is possible that the results may not be representative of the feature as a whole, but, bearing in mind the method of collection, the extent of the feature and the nature of the field evidence, it is suggested that the homogeneity mentioned above is real and not produced solely by chance.

As a final summary of the information obtained from mechanical analysis, Figure VI.2e was drawn to show the limits within which the various deposits were normally located and their relationship to each other.

In addition to comparing the deposits in terms of the different particle size fractions that they contain, some comment must be made concerning the shape of the distribution curves from which the results were obtained. These are reproduced in Figure VI.3. Within the graphs for particular deposits there are variations in the positions of individual curves, but in most cases there is a reasonable similarity in shape, probably most marked in the curves for the Main and Low Beaches. The greatest variety in curve shape is to be found in the samples for the buried fan at Blairdrummond and this may have been produced by the interplay of different geomorphological processes. Most of the samples, for example, were obtained close to the outer edge of the fan where both marine and fluvial processes were probably active.

To facilitate comparison between deposits, average curves were produced (Fig.VI.3a) and they show that the three lines for the buried beaches and that for the carse-clay are strongly related with regard to their shape. All are characterised by a convex curve at the coarse end of the scale with a concave curve at the fine end. At the same time all four of these curves differ from the overall gentle concavity of those representing the recent fluvial deposits and the buried fan at Blairdrummond. Doeglas (1946) has shown that there is a relationship between the shape of the mechanical analysis distribution curve and the environment in which sediments are deposited. Although it was not possible to compare the curves in the present study with those of

Figure VI.3 Particle size analysis
(Curves of cumulative percentage against grain size)



the earlier work, due to variations in recording methods, it is considered that this basic conclusion will still hold true. It would therefore appear reasonable to infer that the carse-clay and the three buried beaches originated in similar environments. Since the marine, or marine-estuarine, origin of the carse-clay is well established the same would apply to the other features, supporting the marine formation already indicated by Sissons (1966) and Newey (1966). In the same way, the correspondence between the curves for the recent fluvial sediments and the buried fan suggests a similar origin, although in this case the variability in the individual curves of the latter, mentioned above, limits the emphasis that may be put on this particular relationship.

Two main points emerge from the results of mechanical analysis. Firstly, after considering the sediment types contained in the buried beaches and the carse, it can be seen that each feature is characterised by a particular combination of the various size fractions. In this way the features can be seen to differ. Secondly, mechanical analysis points to a mode of formation common to each of the buried beaches and the carse-clay.

Heavy Mineral Analysis.

A by-product of the method of particle-size analysis used above, is the separation and collection of the fine sand fraction of the sample. Due to the broad range of minerals commonly found in this fraction, it is frequently used for the examination of the heavy mineral content of sediments. By a process involving flotation, centrifuging and filtering, as explained in Chapter II, the heavy minerals are isolated before being mounted in an immersion oil and systematically identified with the aid of a polarising microscope. Identification is normally accomplished by reference to certain mineralogical properties, such as colour, shape, cleavage or refractive index, but in the present study the minerals were examined mainly by comparison with reference books or specimen slides.

By the study of the heavy mineral content of certain sediments it was hoped to obtain an insight into the source of the materials that now form the buried beaches and the carse. With this in mind, four samples were prepared, including one from each of the buried beaches and one from the carse-clay. In each case, 100-150 minerals were identified and the proportions of individual types were expressed as a percentage of the total.

The sample obtained from the High Buried Beach showed that the minerals of the garnet group were most common with 47% of the total, closely followed by zircon with 41%. The only other minerals in any quantity were chlorite and hornblende with slightly over 5% each. It should be pointed out that the minerals of the iron group were not counted although their presence in fairly large proportions was noted. In terms of origin the iron minerals were probably supplied by the weathering and erosion of Old Red Sandstone rocks, as was the zircon (Waterston, 1965) while the minerals of the garnet group were probably the result of the breakdown of schistose Highland rocks.

The sample for the Main Beach sediments showed certain similarities to that of the High Beach. The percentages of garnet and zircon were still relatively high with 37% and 25% respectively. However, both chlorite and hornblende showed higher values (over 10% each), while traces of augite, enstatite and tourmaline were also recognised. Again, the minerals of the garnet group may well be an end-product of the decomposition of Highland rocks or possibly, to a lesser extent, the result of the erosion of the High Beach. Similar reasoning might apply to the zircon grains. In some areas it was noted that the silty sand of the Main Beach took on a greenish colour and it is suggested that this was due to increased chlorite content. It should also be noted that on examination in the field, the silty sand often had a shiny or silvery appearance and this was explained as due to the mica content of the deposit. During flotation for the separation of heavy and light minerals large quantities of muscovite were floated off as light minerals. Both biotite and chlorite would help to produce the shiny nature of the deposit, also, but it seems likely that the muscovite would be most important in this respect. It is therefore considered valid to refer to the deposits of the Main Buried Beach, in certain areas, as "micaceous silty sand".

The sediments of the Low Beach were also found to be extremely rich in mica. In the sample examined, chlorite and biotite together made up over 90% of the total with only traces of other minerals such as garnet, hornblende and augite. It is likely that the sample used was not completely representative of the beach as a whole, but it does suggest an origin in the schistose rocks of the Highland area west of the Lake of Menteith.

By examining the heavy minerals it was considered that it might be possible to note an increased content of minerals of Highland origin from the High Beach through to the Low, bearing in mind the position of the ice front at the time of formation of the former

(Sissons, 1966). Although this may be represented by the decrease in the zircon percentages and the rise in the mica group, the evidence cannot be entirely conclusive due to the low number of samples used.

As a final step, a carse-clay sample was prepared and the heavy mineral content measured. In this case, a relatively wide range of minerals was obtained, as might be expected from consideration of the age and stratigraphical position of the carse. With 43% of the total, chlorite stood well ahead of garnet and zircon with 18% and 17% respectively. Hornblende, augite and enstatite showed values between 5-10% while traces of tourmaline, epidote, biotite and possibly staurolite were also recorded. The high chlorite content was regarded as a reflection of the clayey nature of the deposit while the greater range of minerals encountered was perhaps related to the greater extent of the carse, compared with the buried beaches, allowing the incorporation of minerals from a wider area. It has to be allowed, however, that this may be a result of the location of the particular sample used and this does apply to all the samples examined here. Thus the results of heavy mineral analysis can only give a picture of the conditions at four specific points in a rather large area.

Pollen Analysis.

Both the Main and Low Buried Beaches have been examined for pollen content in their upper layers and in the peat deposits immediately overlying them (Newey, 1966). Although this work took place on the south side of the Forth, it was considered that the findings would generally apply to the north side of the river also

(Chapter I). However, an attempt was made to analyse pollen from the upper layers of the High Beach and from the overlying peat. Five slides were prepared, three from one site at Powis Mains (NS 8191 9601) and two from a site at Wester Kerse (NN 6526 0001), the material being obtained from the junction between the beach surface and the overlying peat or from the lowest layers of the peat. Four of the slides contained little pollen and were unsuitable for analysis, the fifth was examined and analysed by W.W. Newey. It was obtained from the lowest 2.0 cm of peat resting directly on the beach surface at Wester Kerse, near Thornhill.

Of the arboreal pollens, *Betula* proved to be most abundant with almost half of the 95 arboreal grains counted. The remainder were divided almost equally between *Corylus* and *Salix* with a few grains each of *Pinus, Alnus, Ulmus* and *Quercus*. Of the non-arboreal group, the spores of *Sphagnum* were by far the most common and there was no evidence here of the salt-marsh vegetation found at the junction of the buried peat and the deposits of the Main and Low Beaches to the south of the Forth (Newey, 1966). Considering the relative proportions of the different pollens, Newey came to the conclusion that the peat had been forming during Zone V of the pollen sequence. Indicating this was the prevalence of *Betula* pollen with *Corylus* of secondary importance. The pollen grains of *Ulmus* may represent the first signs of the climatic improvements that took place in Zone VI and, although small in number, they suggest that the formation of the accompanying peat took place in the latter part of Zone V, since Newey (1965) has shown that *Ulmus* began to appear only then in south-east Scotland.

The relative abundance of *Salix* in the analysis was thought to be due to over-representation and it was concluded that the peat resting on the High Buried Beach at Wester Kerse was a Sphagnum peat that probably accumulated in Salix scrub sometime during the latter part of Zone V of the pollen sequence.

Conclusion.

The results of laboratory analysis are somewhat restricted in the contribution that they make to the understanding of the buried raised beaches. Since the original samples were collected as the initial boring was being carried out, knowledge of the adjacent sub-surface conditions was often limited. Working through stratigraphical records, to build up an overall picture of the area under study, it became increasingly apparent that the samples were not always sufficient in number or collected from the points that would have provided the most information. However, this does not invalidate the results that were obtained. Indeed, in many cases, they can be cross-checked with geomorphological or stratigraphical factors, but their numbers and distribution place a restriction on the interpretations or conclusions that can be drawn. The laboratory analysis here is perhaps best seen as resembling a pilot study, inasmuch as the evidence obtained from it, together with the improved knowledge of the sub-carse features, should allow a more comprehensive study to be made of the mechanical and chemical properties of the buried features in the future.

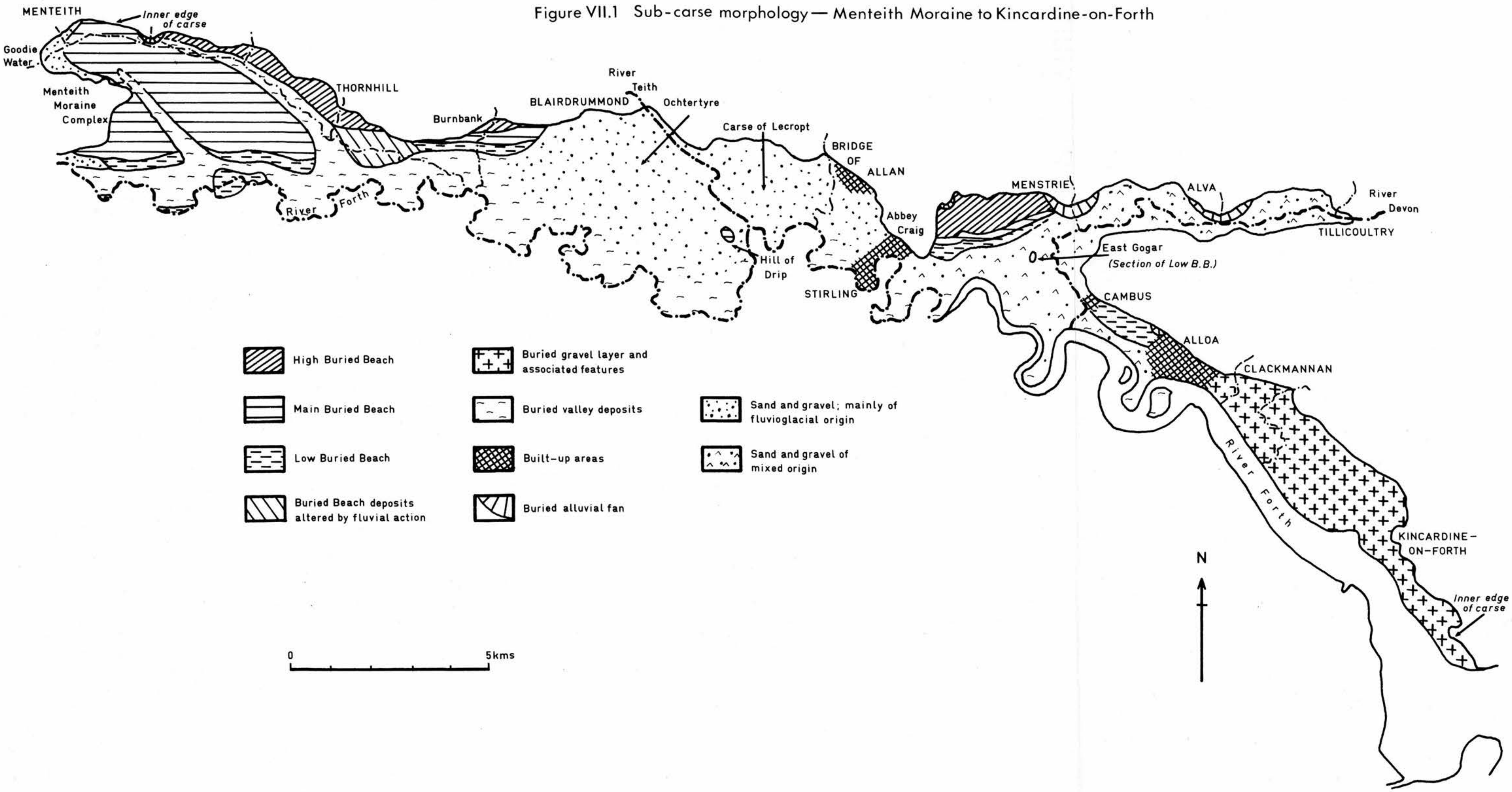
CHAPTER VII

A DISCUSSION OF THE STRATIGRAPHY AND SUB-CARSE MORPHOLOGY OF THE STUDY AREA AND THE SEQUENCE OF EVENTS THAT THEY INDICATE*

In the preceding chapters, it has been shown that the area between the Lake of Menteith and Kincardine-on-Forth can be divided into a number of smaller regions based on the sub-carse morphology. As in most cases where division is required, the boundaries are not absolute, but are based to a greater or lesser degree on convenience. For the three sub-areas already identified there are certain factors that make them decidedly different from each other, yet there are also factors common to all three. Some of these linkages from one area to another have already been indicated and the purpose of this chapter is to consider them more fully, at the same time examining the origins and relationships of individual features within the areas allowing a more comprehensive picture of the complete region to be built up. Furthermore, it has been pointed out above (Chapter I) that the present study is concerned mainly with the evidence of geomorphological activity during a period beginning with the maximum of the Zone III Readvance and terminating with the flooding of the Forth valley by the carse-sea. This being so, it is intended, in

*Figure VII.1 is applicable to this entire chapter.

Figure VII.1 Sub-carse morphology — Menteith Moraine to Kincardine-on-Forth



the first place, to consider the situation leading up to the point when ice stood at the Menteith Moraine, introducing other events, and the features associated with them, as far as possible in chronological order.

* * *

The Loch Lomond Readvance culminating about 10,300 years ago marked the last major Weichselian expansion of ice in Scotland. At its maximum, the ice moved from the Highlands into the head of the Forth valley, perhaps even extending its snout into a sea that stood at about 10.0 m O.D., and produced a conspicuous moraine (Chapter I). The moraine itself indicates a period of equilibrium during which the rate of ablation more or less balanced the rate at which new ice was being supplied, great quantities of outwash sands and gravels meanwhile being carried out into the sea.

One of the constituents of the moraine is a fossiliferous marine clay gouged out and redeposited by the advancing ice. From an examination of the included shells and comparison with similar deposits in the Loch Lomond area it has been concluded that the clay was laid down in an arctic climatic environment (Simpson, 1933), while radio-carbon assay has provided a date of 11,800 B.P. for the shells themselves (Sissons, 1967b). The term "arctic" as used by Simpson may be questioned as it is known that the Zone II period into which the sediments have been dated showed some climatic amelioration (West, 1968), compared with the preceding period, but it does not prevent the use of the term "Lateglacial marine clays" for these deposits.

Before, during and after the Perth Readvance, provisionally dated as reaching its maximal extent about 13,000-13,500 B.P., marine incursions deposited great thicknesses of silts and clays in the Forth valley. These have been examined in the Grangemouth area at various times since the second half of last century (Milne-Home, 1871; Cadell, 1880, 1913; Dinham and Haldane, 1932; Sissons, 1963, 1967a) and the general concensus of opinion, based largely upon the nature of included fossils is that the sediments were laid down in arctic waters.

Within the readvance limit, which, according to present evidence lay across the Forth valley in the vicinity of Kincardine (Smith, 1965), the arctic silts and clays were probably eroded or incorporated in newer deposits while outside the limits they were covered by sands provided by meltwater rivers. Most of these sands were redistributed by marine action to produce beaches later raised by isostatic adjustment (Chapter I). At the same time, away from the inner margins of the estuary the finer sediments were being deposited to continue the accumulation of Lateglacial marine sediments. At this point, then, the term "Lateglacial marine" has been applied to deposits formed prior to and during the Perth Readvance.

With the decay of the ice after the maximum of the readvance, the glacier margin retreated as far as the Stirling gap where a substantial halt or slight readvance took place. The retreating ice was replaced over the area between Stirling and Kincardine (including the Devon valley) by the advancing sea. The beaches associated with this sea now occur up to 38.0 m O.D. immediately east of Stirling, while clays or silts, reddish or reddish-brown in colour, are recognizable in numerous boreholes in the area. The clays and silts rest upon till in many places or may be separated from it by sand and gravel of probable fluvioglacial origin, while the fossils that they contain show them to have been deposited under arctic climatic conditions (Parthasarathy and Blyth, 1959).

While ice stood in the Stirling gap, the sea-level fell relative to the land as is indicated by the discrepancy in raised beach heights east and west of Stirling (Sissons and Smith, 1965a). West of the city no raised beach has been found above 23.0 m O.D. Despite the fall in level, however, the sea remained sufficiently high to cover a large area west of Stirling vacated by the decaying ice, leaving evidence of its presence in the fine clays and silts of borehole reports, and shells apparently associated with this incursion have been dated at 11,800 B.P. (Sissons, 1967b). Since the deposits from which they were obtained were not *in situ* it was not possible to link the date directly to a particular sea-level.

One of the main problems in this area is the paucity of deep commercial boreholes in which the Lateglacial silts and clays can be identified. Where they are present their surface varies in height from -10.2 m O.D. at Lecropt to +6.9 m O.D. at Blairdrummond. Farther west at Inch of Leckie and Bridge of Frew respectively, heights of -3.0 and -6.9 m O.D. have been measured, while at West-wood, between Blairdrummond and Lecropt, the surface of the clays and silts lies at +2.3 m O.D. In only one small area is there any obvious pattern to the altitude of the deposits and that is in the Carse of Lecropt where the borehole density is somewhat greater than elsewhere. Here, the Lateglacial deposits have been identified in a total of 19 boreholes. With one exception the surface of the deposits has been heighted at between +1.0 and -4.1 m O.D. and in twelve bores they lie within the narrower range +1.0 m O.D. to -2.0 m O.D. In addition to this, in the same area, where the clays and silts are missing from the stratigraphy, their place is taken by rock and till with surface heights falling within the same range. Furthermore, in one particular bore, the clays and silts are covered by a layer of brown sand and gravel 1.4 m thick while what is probably the same deposit can be identified in another borehole where it contains marine shells and rests upon a till surface at -0.2 m O.D. Unfortunately, shells are recorded only in one case but the concordance of levels from clay and silt to rock and till strongly suggests marine activity associated with a sea-level close to or slightly below Ordnance Datum.

Beneath the carse clay in the Grangemouth area, Sissons (1969) has identified a platform of marine erosion ranging in altitude from -6.0 m O.D. to +6.0 m O.D., but with the bulk of the erosion concentrated at or about present O.D., while a continuation of the feature to the north of the Forth has been described in Chapter V. There are several similarities between that feature and the one outlined in the Carse of Lecropt. In both areas the height ranges, within which the features lie, are closely comparable while the nature of each surface, truncating rock, till and silts and clays, is also similar. At the same time, marine shells have been found associated with both features.

As well as the similarities, there are differences, but most can be explained in terms of slight differences in local environment. A characteristic of the platform in the Grangemouth-Kincardine area is the widespread presence of a relatively thin gravel layer. Such a layer may be present at Lecropt, and it has possibly been located in one or two boreholes, but the stratigraphy is such that the silts and clays are often overlain by thick beds of sand and gravel that could make identification of the equivalent of Sissons' "buried gravel layer" very difficult. A slightly more sheltered environment at Lecropt might also explain the difference.

A more serious problem would seem to be the height relationship between the two areas. Taking isostatic factors into consideration, it might be expected that any equivalent of the Grangemouth-Kincardine feature in the west would have a greater altitude than the more easterly feature. Comparing altitudes at Lecropt and Grangemouth-Kincardine it can be seen that this is not so. However, several factors can be taken into account when examining this discrepancy. In the first place, since no shoreline has been located at Lecropt, it is not possible to decide the point on the Grangemouth-Kincardine feature from which heights should be taken for comparison. Again, in the Grangemouth-Kincardine area, while no shoreline gradient has been calculated, the general altitudes show little or no downvalley slope. This appears to be so at Lecropt also and as a result the height differential between the two areas would be expected to be low. Finally, at Grangemouth-Kincardine the Late-glacial sediments are overlain by a layer of gravel as much as 1.5 m thick, but commonly between 0.3 and 0.9 m, while at Lecropt the stratigraphy does not normally include such a layer. Depending upon the point at which the heights were measured, this in itself might have the effect of reducing the altitudinal differences. It would appear evident that the height relationship between the two areas is less serious than at first considered and, in fact, the general correspondence in height linked to the factors presented above does not preclude the two surfaces from being considered as separate parts of the same feature, namely a platform of marine erosion formed by a sea-level close to that of the present day.

This period of low sea-level has been provisionally dated by Sissons (1967a) as occurring sometime between 13,500 B.P. and 10,300 B.P. (Chapter I). It would seem possible, however, to reduce this time span somewhat. It is well established that the sea-level in the Forth valley was much higher than at present when the Perth Re-advance ice began to decay. Although the level did fall relatively rapidly while the ice front stood in the Stirling gap, it remained sufficiently high to produce the beaches now standing at about 20.0 m O.D. west of Stirling. Thus, the sea-level could not have been low enough to produce the buried gravel surface during the early part of the period. Timing the continued lowering of sea-level is a main problem in the Forth area (and during the period concerned) because of the limited number of radio-carbon dates available. In addition, results from other parts of the country can be applied only in a general way. Evidence from Northern Ireland, for example, suggests that the sea had fallen below its present level by 12,000 B.P. (Morrison and Stephens, 1965) and this agrees with the general trend established in the Forth. However, the distance of the areas from each other and their individual distances from the centre of isostatic uplift limits the usefulness of the comparison. Shells from sub-arctic clays incorporated in the Menteith Moraine have shown that marine sedimentation was still active there as late as 11,800 B.P. This being so, these clays must represent the latter stages of deposition from the sub-arctic seas, since close to the date obtained the Zone II amelioration of climate was beginning to take place. Due to the fact that the shells and surrounding sediments are not *in situ*, their altitude is not suitable for the estimation of sea-level, but Sissons (1967a) has inferred that the sea had fallen to about its present level, or slightly below, by the time the sub-arctic deposits of Scotland had ceased to accumulate. It is suggested, therefore, that the low sea-level in the Forth valley was reached slightly after 11,800 B.P. and by that time marine erosion was beginning to produce the surface characterised by the buried gravel layer.

As has been pointed out in the Grangemouth-Kincardine area the buried gravel surface and associated planated rock and till is encountered through the considerable range of -6.0 to +6.0 m O.D. and exists as a continuous feature within that range. It is considered that such a result would be produced by a gradually rising sea-level with the rate of rise balancing the rate of erosion and allowing the extension of the feature both altitudinally and areally. As the sea reached present datum, the rise may have slowed slightly, explaining the abundant records at about that height.

To return to the dating of the formation of the buried gravel layer and its related erosional surface, it is suggested that they were produced by the erosion of Lateglacial marine sediments, till and rock sometime between 11,800 B.P. and 10,800 B.P. With a time span of only 1,000 years, it might be argued that such a period would be insufficient to produce extensive erosion. However, certain local conditions that might accelerate erosion can be suggested. In the first place, it seems likely that some erosion accompanied the sea-level as it fell to its low circa 12,000-11,800 B.P. The steady rise in sea-level that followed could have made use of this in the formation of the final surface. Furthermore, in the area concerned, deposits such as Lateglacial marine sediments and till contain abundant rock fragments ranging in size from pebbles to cobbles and boulders, held together by finer materials such as clay and silt. The relatively easy erosion of the latter would make available sufficient of the larger constituents to allow reasonably rapid erosion of the adjacent rock, while the possibility of at least some glacial erosion of the rock surface, followed by modification by marine agencies, cannot be overlooked. Other factors such as increased storminess in the Forth may also have helped erosion, but it is thought that a combination of the circumstances mentioned would allow the buried gravel layer and its counterparts to be formed within the allotted time.

Considerable space has been used in an examination of these deposits normally termed "Lateglacial marine sediments", for two main reasons. Firstly, the term has been used somewhat loosely in the past. Part of the problem has been the limited information available and this remains a major difficulty. However, an attempt has been made above to show that deposits identified by that name are not necessarily of the same age. Secondly, in the Forth valley, this period of considerable geomorphological activity produced a base for the development of the later features with which the present study is more directly concerned and for this reason it was considered necessary to look at it, with its associated features, in some detail.

Buried outwash and associated gravel deposits.

Associated with the Menteith Moraine are a number of areas of outwash sloping eastwards down the Forth valley and indicating considerable meltwater activity as the ice of the Loch Lomond Re-advance decayed. On the north side of the Forth, the main mass of fluvioglacial gravel forms an outwash plain spreading out from a gap in the moraine now occupied by the Goodie Water, a small stream draining the Lake of Menteith. This outwash can be followed in an easterly direction for more than 3.0 km and over part of this distance it is buried beneath more recent deposits (Fig.III.2). Considering its relationship to the moraine, the formation of the outwash can be employed as a point of reference for the dating of these deposits. Previous work on this aspect has been described above in Chapter I and as the present study can add little to this, it will concern itself, at this stage, with sand and gravel deposits thought to have been formed contemporaneously with the Menteith outwash.

All along the northern edge of the carselands, between the Menteith Moraine and Blairdrummond, the streams passing out on to the carse show evidence of alluvial fan development. In most cases the fans can be seen to rest upon the carse, indicating relative ages, but boring has provided evidence that shows that fan formation began in Lateglacial times. At Rednock, Tarr and Ruskie, for example, not only do the fans pass beneath the carse, they also pass below the buried beach deposits. The Rednock Burn gravels are overlain by the grey silty sand of the Main Buried Beach, while the deposits of the High Beach rest on parts of the fans at both the other locations. Thus the lower parts of the fans are at least older than the High Buried Raised Beach. Furthermore, since the sediments of the latter ceased to be laid down in a very short time following the deposition of the outwash (Sissons, 1966), the fans cannot be younger than the outwash. They may have been initiated some time before this, but considering the environmental conditions associated with a decaying ice-sheet, it is probable that the fans were largely built up at the same time as fluvioglacial deposition was taking place downstream from the moraine, and, although the stratigraphical evidence is less positive elsewhere, it is suggested that the other fans at Rednock, Boquhapple, Norrieston, Craighead and Burnbank were growing at the same time.

Although considerably smaller, the features west of Blair-drummond are somewhat similar to the fans along the face of the Ochils, for which the stratigraphy and period of formation have been described in some detail in Chapter V. Unfortunately, no commercial boreholes pass through the former, but the overlying stratigraphy does show that they were well developed prior to the deposition of the buried beaches and continued to grow following this, as was the case with the Ochil fans. In the latter area, development appears to have been initiated while an arm of the sea extended into the Devon valley with the decay of the Perth Readvance ice, but in the west the initial growth must have come later as the ice retreated westwards. Nevertheless, whatever the time of origin, it is probable that both sets of fans were substantially augmented during the period of glacial decay that followed the Loch Lomond Readvance. While none of the fans was directly connected to a glacier outlet, and none was therefore supplied with glacial meltwater, it is considered that the melting of permanent or semi-permanent snow on the Menteith and Ochil Hills would add sufficiently to the supply of water to allow an increase in the transport of material abundantly available in unconsolidated periglacial and glacial deposits, to the fans.

Furthermore, from a climatic point of view, there appears to be no period between the end of the Zone III cold spell and the wetter Atlantic period during which there would have been sufficient water available for deposition of coarse material on such a scale (Manley, 1952). Since then, the fans have continued to grow from time to time, but, especially after the formation of the carse, the detritus has tended to be of a finer nature -- sand or coarse sand compared with the earlier gravel or sand and gravel -- and this is probably a reflection of a relative decrease in the vigour of the elements of erosion and deposition in more recent times.

The features considered above are small when compared with the alluvial fan of the River Teith. With its extension eastwards to Stirling, it covers a total area approaching 18.0 sq km while it is directly connected to gravel terraces in the Teith valley immediately adjacent to the present study area (Fig.VII.2). These terraces provide an insight into the origin of the fan, for it appears that they have been formed by the dissection of an outwash train that once filled the valley (Smith, 1965). Followed south-eastwards down the Teith, the terraces pass beneath the carse clays, but boring has shown that they form a continuous unit with the buried fan that spreads out from the point of exit of the river from the hills at

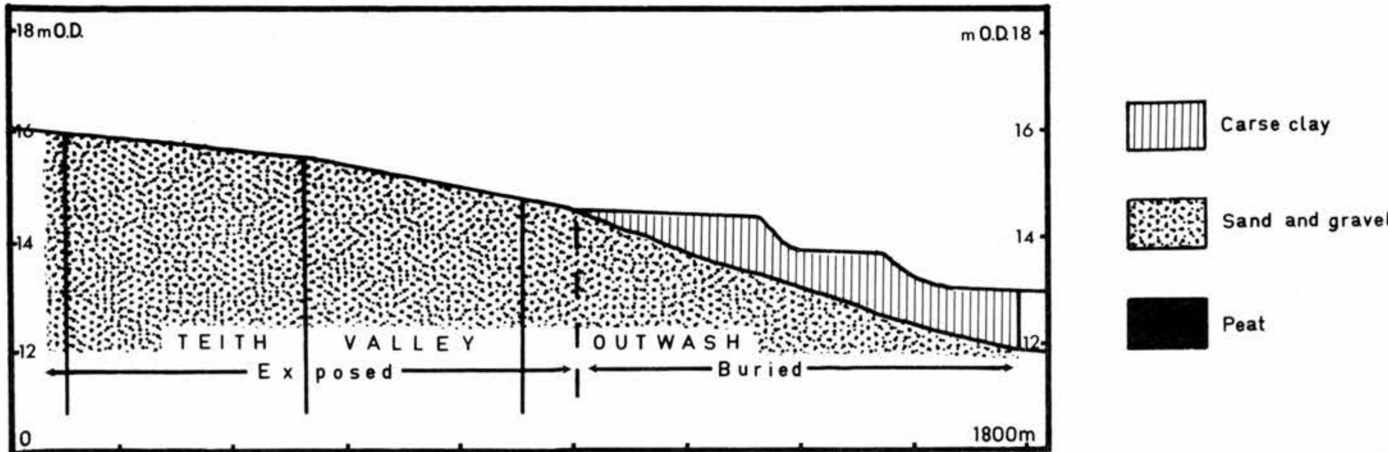


Figure VII.2 The sand and gravel deposits of the River Teith, near Blairdrummond (Various sources)

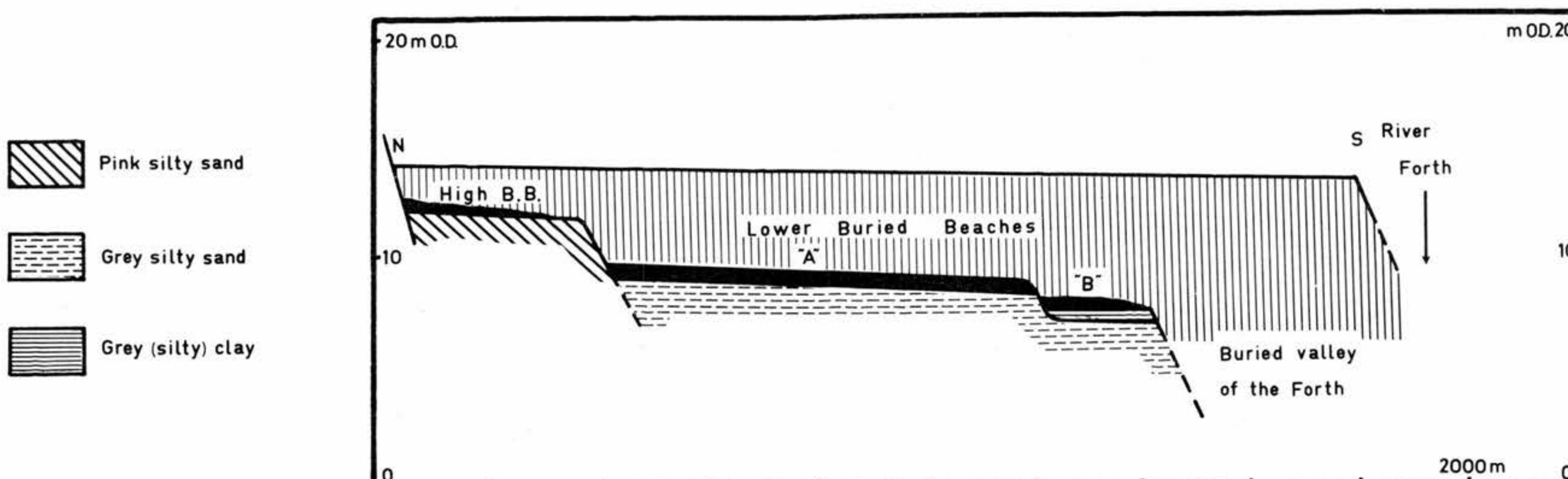


Figure VII.3 The buried beaches on the northern side of the River Forth

Blairdrummond (Chapter IV). The close link between fan and terraces suggests a common origin and it is considered that both were formed initially from fluvioglacial material carried down the Teith and out towards the Forth. Subsequently, the erosion that caused the formation of the terraces probably brought about an extension of the fan with the re-deposition of sands and gravel, while the changing course of the river undoubtedly altered its morphology.

Given the proposed fluvioglacial origin of the buried fan, the problem of dating its formation arises. The most recent glacial period with which fluvioglacial agencies can be associated is the Zone III Readvance. In the Teith valley, the exact limits of this event have not been located, but it is known that the ice extended to the vicinity of Callander (Sissons, 1965), and from that position meltwater could have carried the outwash downstream towards Blairdrummond. It is conceivable that during retreat after the Perth Readvance the Teith might have acted as routeway for meltwater carrying fluvioglacial material, but in the immediate area there is only one deep borehole and this does not allow any conclusions to be drawn.

Initially a roughly symmetrical fan might have been built up by a number of distributaries that frequently changed their courses as is common in such situations (Strahler, 1969). With time the bulk of the drainage became channelled into the main stream of the Teith and the deposits were spread out eastwards at least as far as the Hill of Drip and the Carse of Lecropt, but perhaps even reaching Stirling. Even today, the Teith carries gravel eastwards as can be seen in the bed of the river from Mill of Torr to Lecropt and at

Heathershot where a substantial mass of sand and gravel rests upon the carse and forms the core of a meander. Lenses of gravel within the carse, but away from the present line of the river are presumably indicative of a similar origin while the carse-clays were being deposited, indicating (together with the earlier and more recent evidence) the continuing ability of the Teith to transport coarser sediments from its valley on to and across adjacent lower areas. Assuming an abundance of meltwater during the decay of the Zone III ice and considering the borehole evidence of changes in position of the riverbed (Fig.IV.2), it seems entirely feasible to credit the waters of the Teith with the formation of the buried fan in the vicinity of Blairdrummond.

The above observation would appear to hold true for Lecropt also, where formlines on the surface of the buried gravel indicate a former course of the Teith through the area (Fig.IV.4). However, slight additions are required. In the western part of the Carse of Lecropt, close to the present River Teith, the buried gravel is commonly represented by a single band varying in thickness between 3.6 and 5.0 m and resting upon sediments interpreted above as Lateglacial in age. Contrasting with this in the east are a number of boreholes that show the gravel nowhere less than 10.0 m thick, with a maximum of 19.0 m, while the total thickness consists of a number of bands varying in texture from fine sand to large gravel, the whole overlying silts and clays similar to the Lateglacial sediments or occasionally till.

One explanation of the difference involves an examination of rockhead altitudes in the eastern and western parts of the Carse of

Lecropt. Although not all boreholes have reached rockhead, those that have, show lower altitudes in the east than in the west, by as much as 10.0 m and point to the possibility of a deeper basin to the east in which great masses of sand and gravel accumulated. The existence of such a feature could only be proved by additional deep boring, but, whether or not it is present, the extra material could have been supplied from local sources. Close to the eastern edge of the area, the Lecropt Burn and the Allan Water enter the carselands and it seems probable that the complexity of the gravel stratigraphy can be explained by the conditions produced at the confluence of these streams with the Teith.

In a few cases, where the gravel directly overlies till, a further possibility exists. The last ice to cover the area did so at the time of the Perth Readvance and it was presumably then that the till was deposited. With the retreat of the ice, and its halt in the Stirling area, fluvioglacial detritus was laid down in the form of a major terrace in the Bridge of Allan area (Dinham, 1927; Smith, 1965). Some material may well have been carried on to the ice itself to be deposited directly upon the till as the ice melted. With continuing deposition, especially following the Loch Lomond Re-advance the present thickness of gravel was built up. Given the number and distribution of deep boreholes, this can remain only a possibility, although, considering the composite nature of the Ochil fans and the local site conditions, it would not seem out of place as part of the explanation for the accumulation of such a large volume of sands and gravels in this particular location.

In summary, it can be noted that while the ice of the Zone III

Readvance was decaying at Menteith and causing the development of an outwash plain in the upper Forth about 10,300 B.P., sand and gravel was being carried into the Forth basin at numerous points along its northern edge, to form or expand alluvial fans. Of these, the Ochil fans had already been in existence for a period of perhaps 2,500 to 3,000 years while fluvioglacial and fluvial gravels may have begun to accumulate slightly after this immediately west of Stirling. The period of initiation of the fans between Blairdrummond and Menteith cannot be deduced with any certainty, but it is considered that all were substantially augmented during Zone III, especially during the retreat of the ice and this appears particularly true in the case of the Teith fan. At a later date, the lower portions of most of the fans and virtually all of that of the Teith were buried beneath the deposits of the carse sea. Since then the fans have continued to grow, but less vigorously and this is reflected in the finer materials lying above the carse compared with those buried by it. Even today most of the fans are active, if only intermittently and in the case of the Ochil fans this represents continuing activity over a period of approximately 13,000 years.

The High Buried Raised Beach.

The above term was first used by Sissons (1966) in referring to a terrace or step lying close to, but slightly lower than, the carse shoreline in the western part of the Carse of Stirling, south of the River Forth. In this location it was covered by a layer of carse-clay 2.0-3.0 m thick, but separated from it by a thin band of peat. Since it is composed of fine-grained water-laid sediments that were adjudged to be of marine-estuarine origin and since it was both buried beneath the carse-clay, yet standing at a height above present Ordnance Datum, the term "buried raised beach" was applied to the feature. Further examination showed it to be only the highest of a suite of buried beaches, therefore the prefix "high" was added. In the area in which it was first identified, the beach was characterised by a major proportion of silty sand in its composition, the components being pink or pale-brown in colour except in the upper few centimetres where grey was more common. Finally, since altitude was being used in the differentiation of this beach from adjacent features, particular attention was paid to heights and levelling showed that close to its shoreline most of the surface stood within a range of 11.9 to 12.3 m O.D.

The present study has shown that there exists a comparable terrace extending for a distance of some 6.0 km downvalley from the Menteith Moraine along the northern edge of the carselands. In virtually every respect, the two beaches show a strong similarity that stretches through colour, composition and position with respect to adjacent features. Some differences are to be expected due to variations in local conditions, but any that do exist are relatively small. On the northern side of the Forth, for example, one borehole shows the High Buried Beach at a height of 12.9 m O.D. compared with a maximum of 12.3 m O.D. to the south. With reference to the buried peat layer that normally covers the surface of the southern beach to a depth of a few centimetres a further variation may be noted. To the north, the peat has been found to vary from almost nothing to as much as half a metre in thickness, but again this may be explained by small local differences in factors such as drainage. Overall, the differences are by far outweighed by the similarities and there appears to be no doubt that the two beaches represent the same period of marine-estuarine deposition.

Boreholes put down to the High Buried Raised Beach show that it exists without a break between Ruskie, close to the moraine, and Ballinton, almost 6.0 km to the east, with an altitudinal range of 12.8 to 10.3 m O.D. between these points. Absent for 2.0 km east of Ballinton, it appears again at Burnbank where it consists of a triangular area of coarse grey or pink sand and silty sand resting beneath an embayment in the carse shoreline with its apex at the point of entry of the Burnbank Burn on to the carse. Heights along the inner margin of this section range between 11.1 and 10.2 m O.D.

An examination of the sediments forming the feature bring to light two main points; firstly, a reduction in the coarseness of the deposits away from the inner margin and secondly, a change in colour and sometimes texture with depth. Close to the higher land, pink or red sandy gravel is often present immediately beneath the carse, in some cases mixed with grey sand (Boreholes 184, 185, 187, 670, and 697), and as the re-entrant of the Burnbank Burn is approached, the texture becomes noticeably coarser. As noted, similar changes are sometimes present with increasing depth in the deposits (Boreholes 691 and 696), but the most remarkable change is in colour. In this area, boreholes commonly reveal the following stratigraphy:-

4. Carse clay
3. Peat
2. Grey silty sand
1. Pink (silty) sand

The grey silty sand averages 20.0-30.0 cm in thickness and closely resembles the weathered layer normally associated with the surface of the High Beach (Chapters III and V).

From this evidence an attempt was made to deduce the origin of the feature. It was pointed out above that the Burnbank Burn is considered to have been one of the streams building fans out into the Forth valley at the time of the Zone III advance. This, plus the addition of material by mass-movement from the slopes rising behind the carse is regarded as having supplemented marine deposition at that time. It would also explain the increasingly coarse nature of the material towards the backslope and towards the stream. From the nature of the sediments, the form and the location of the feature, it is thought to represent the High Buried Raised Beach in this area.

Downvalley from Burnbank, the High Beach has not been encountered at all over a distance of 12.0 km. In a study such as this, the spacing of boreholes might prevent the identification of a feature, but, in this particular area, the location of individual boreholes or groups of boreholes is such that this appears rather unlikely and it is believed that either the High Buried Beach is non-existent in this area, or, if it does exist, the patches are extremely small (Chapter IV). Beyond Stirling, a feature that is in many respects similar to the High Buried Beach has been identified along the Ochil front from Abbey Craig at Stirling to Menstrie in the Devon valley (Chapter V). Thus, over the area concerned, two buried beaches that are possibly related to each other are present, but well separated by an area in which no comparable landform can be located. From these points, two questions arise. Firstly, is the feature east of Stirling a more easterly section of the High Buried Raised Beach? Secondly, why is the High Beach absent between Burnbank and Stirling?

For purposes of comparison, the two beaches can be examined in terms of a number of factors including form, colour, composition and stratigraphy. (Shoreline gradients can be compared also, but these will be considered separately along with the results from other beaches in Chapter VIII below.) Of these, similarities in surface form and colour are probably most obvious. Both sections are composed largely of pink or purple-pink sediments, the surface of which deviates little from the horizontal and has been only slightly dissected (Figs.III.4 and V.5). As the northern margin of each beach is approached the colour becomes more brown than pink and the surface becomes slightly hummocky perhaps due to the abundance of material supplied by solifluction or general downslope movement. The colour comparison can be carried further. It was pointed out (Chapter III) that in the High Buried Beach in the west, the topmost 5.0-10.0 cm were commonly greyish in colour rather than pink as if the sediments, originally pink, had been discoloured in some way. Such a discolouration is a normal feature of the buried beach along the Ochil front where it may affect the upper 10.0-20.0 cm of the deposit.

With reference to composition both similarities and differences exist. The general term "silty sand" has been used to cover the majority of sediments on both beaches, but, while it is almost everywhere applicable to the western section, there are significant differences in the east. Mechanical analysis has shown that on average the High Buried Beach in the west is the coarser of the two

(Chapter VI). However, in both areas, increasing coarseness of the beach material is apparent as the inner edge of the feature is approached and this is particularly so if alluvial fans are present. In the east, average values mask the coarseness of individual samples due to the modification produced by figures from an area in which pink clay, rather than pink silty sand, predominates. The clay has been found mainly in the angle between Abbey Craig and the Ochils and it is thought that the preponderance of fines -- as much as 73.5% of silt and clay in one sample -- is due to a location some distance from the source of the coarser materials, for the beach is over a kilometre wide at this point. This is the main textural difference between the two features, but it is thought that it can be explained in terms of local variations in sedimentation and does not preclude the possibility that they might be separate parts of the same beach.

In each case, the buried beach is only one element in the stratigraphy and the relationship with the deposits both above and below can be utilized to extend the comparison between the eastern and western features. In many places, the beaches proved too tough for penetration beyond the uppermost 10.0-20.0 cm with the Hiller borer and this imposed certain restrictions throughout the study. Nevertheless, where the deposits were thin or soft enough for penetration and where deeper commercial boreholes were available, the results showed a consistency that is common to both areas and has been summarised in Table VII.I.

TABLE VII.I

Sample boreholes from the Thornhill area and from south of the Ochil Hills, showing typical stratigraphy

THORNHILL	SOUTH OF OCHIL HILLS
Borehole 636 (NS 6368.0044)	Borehole 527 (NS 8162.9616)
4. Carse	4. Carse
3. Peat	3. Soft woody peat
2. Pink silty sand grading to pink sand	2. Brown-pink silty sand
1. Coarse sand and gravel	1. Coarse sand and gravel

It is suggested that the close correspondence between the stratigraphical columns, together with similarities in form, colour and composition allows the buried beach between Abbey Craig and Menstrie to be considered as an eastern counterpart of the High Buried Raised Beach of the Thornhill area.

A second problem that might be discussed at this point is the absence of the High Buried Beach in the area between Blairdrummond and Stirling. Taking heights on the beach section at Burnbank into account, it could be expected to stand between 9.0 and 10.0 m O.D. at Blairdrummond. Although the buried gravel in that area reaches heights of 11.0 m O.D. it slopes southwards and eastwards to well below 9.0 m. Thus, while the upper parts of the gravel would stand above the High Beach sea-level it might be expected that the beach sediments would form an apron over the lower areas. The borehole evidence shows that this is not so. As indicated the development of the High Buried Beach in the west took place after the deposition of the main mass of outwash and it is suggested that the outwash continued to be laid down at a later date in the Blairdrummond-Stirling area than farther west. At Menteith the local topography was such that as soon as the ice left the moraine the influence of meltwater on the depositional environment was severely restricted for its only exit eastwards was through the gap now occupied by the Forth. In contrast, coming mainly from the Teith, the meltwater farther east was being collected from a larger catchment area than at Menteith and had access to larger quantities of outwash. Fluvio-glacial activity therefore persisted for a greater length of time than in the west disrupting the depositional conditions necessary for the formation of the beach. Any beach-form that did develop could have been destroyed or rendered unrecognisable by the changing positions of distributary streams on the fan. This possibility is strengthened by the fact that beaches formed after the High Beach do, in fact, encroach upon the fan in places, presumably owing their existence to a reduction in the vigour of fluvial activity.

In conclusion, it can be noted that the High Buried Beach exists as a recognisable entity in two areas on the northern side of the Forth valley, separated by a third area in which it may never have been present or may have been so altered as to retain no properties in common with the beach in adjacent areas. The High Buried Beach appears to have been formed from materials carried into the sea from the west and to a certain extent as a result of erosion of and mass-movement from Old Red Sandstone sediments and volcanics that formed the coastline at the time of its formation. In the present study it did not prove possible to obtain an independent date for the final formation of the feature, but stratigraphical considerations support the date of 10,300 B.P. postulated by Sissons (1966) for the corresponding beach on the south side of the Forth.

The Lower Buried Raised Beaches.

Of all the buried beaches, the High Beach with its pink coloration and position beneath the innermost edge of the carse is perhaps most distinctive. At lower levels, however, a number of other features have been located, easily distinguishable from the High Beach in terms of colour and composition as well as height but with similarities that can make them difficult to separate one from the other. These are the grey buried beaches composed of silty sand or clay lying to the south of the High Beach where it is present and at altitudes 1.0-4.0 m lower. They can be compared with the Main and Low Buried Raised Beaches of Sissons (1966) but in a number of respects the comparison requires some qualification.

The lower buried beaches have been found mainly in two areas, corresponding to those in which the High Beach was located, namely the area between Menteith and Blairdrummond and that between Stirling and the Devon valley. In addition, the lower beaches have been found to rest upon the Teith gravels, an area from which the High Beach appears to be completely absent. Within the two main areas mentioned, the lower beaches do not form the continuous features that the High Beach does and much of the difficulty in their interpretation is related to the fact that they form a number of isolated patches with only slight altitudinal and stratigraphical differences.

Although the various beaches have already been described in detail (Chapters III, IV and V), a short recapitulation will allow their locations and characteristics to be brought together for analytical purposes. In the area between the Menteith Moraine and Blairdrummond, the lower beaches are divided into two sections, just south of Thornhill, by the buried channel of the Goodie Water, which also separates the lower beaches from the High as far west as Ruskie where the latter appears to end. Eastwards from Thornhill, the High Buried Beach is encountered only in a small section at Burnbank and one of the lower beaches lies beneath the inner edge of the carse as far as the buried fan at Blairdrummond.

In the western section the lower beaches are two in number, differing mainly in terms of altitude and composition (Fig.III.4). Similarities in these two factors invite comparison with two buried beaches described by Sissons (1966) in the same general area, but to the south of the River Forth, and the higher beach on the north, composed of grey silty sand has been provisionally correlated with Sissons' Main Buried Beach, while the lower, composed of grey clay or grey silty clay, has been linked with the Low Buried Beach of the same sequence. In contrast to the normally distinctive features that characterise the Main and Low Beaches of the western section, there is considerable variety in altitude and composition in the stretch between Thornhill and the Blairdrummond fan. Although in terms of morphology there appears to be only one continuous feature (Fig.III.6) it varies in composition from relatively coarse grey silty sand to fine grey clay and in altitude from 10.8 to 8.5 m O.D. Mainly on the basis of composition and stratigraphy, this section was considered to contain parts of the Main and Low Buried Beaches.

Across the area underlain by the Teith gravels as far east as Stirling, the occurrence of the lower beaches is extremely limited.

In only two small areas at Sommer's Lane and Hill of Drip have buried beach sediments of any kind been located. They consist of grey or grey-green silty sand and from a general consideration of altitude, form and composition, it was concluded that they belonged to the Main Buried Raised Beach. With the analysis of the distribution of the lower buried beaches as a whole, this supposition may benefit from further examination.

Moving eastwards beyond Stirling, two lower beaches have been identified along the southern edge of the High Buried Raised Beach between Abbey Craig and Menstrie (Fig.V.5) with minor patches at East Gogar and Cambus. The latter is the most easterly location of any of the buried raised beaches on the north side of the Forth, excluding the buried gravel layer which, although marine in origin, differs morphologically and texturally from the other buried beaches. The features bordering the High Beach are relatively narrow, composed mainly of grey silty sand and stand at two different levels, the distinction being more obvious at Abbey Craig and less so nearer Menstrie. Although both are very similar in composition, the sediments of the upper beach overlap the southern edge of the High Buried Beach, which appears to have been eroded slightly, and this has a bearing on the stratigraphy. Pink silty sand is present beneath the sediments of the upper feature but not the lower. On the basis of this and a height difference of 1.0-2.0 m, a distinction was made between the two. From their position with relation to the High Buried Beach it was considered that the lower feature represented the Low Beach while the sediments resting upon the edge of the High Beach were part of the Main Buried Beach. Mainly on altitudinal and stratigraphical grounds, the smaller sections at East Gogar and Cambus, were assigned to the Low Buried Beach.

In establishing the relationships between the beaches of the region as a whole, comparison was made initially with the system established by Sissons (1966) for an area in the western part of the Carse of Stirling, mainly south of the River Forth. The situation in that area involved a relatively simple buried morphology with three beaches in a sequence in which the highest was oldest and the lowest was youngest. On the assumption that such a sequence would present itself in whole or in part, elsewhere in the Forth valley, it was taken as a reference. Within the three sub-divisions of the study area, each beach was assigned to one of the categories of High, Main or Low, in line with the sequence, which proved relatively easy where judgement was attempted within individual areas. Even with comparison between adjacent areas similarities were present, being strongest in the case of the two features considered equivalent to the High Buried Raised Beach. With the lower beaches, the similarities were less strong, necessitating slight changes in the basic system.

While the initial assumption, that the original sequence would be present, in whole or in part, in more than one area in the Forth valley, appears quite valid, several points arise. The boundary between comparison of features and the fitting of features into a preconceived sequence is a very narrow one and with this in mind the northern beaches were re-examined, in isolation, in an attempt to establish a pattern that could be compared as a whole with the sequence to the south of the Forth. This was applied only to the lower beaches, however, since it was considered that the similarity between the highest beaches both north and south of the Forth was sufficiently strong to leave little doubt as to their common origin. In itself, this was not thought to invalidate the technique since it can be taken to mean that the upper element of any pattern recognised north of the Forth is already comparable to the upper element of the sequence south of the river. The factors taken into account when comparing the High Beach sections at Thornhill and east of Stirling were again employed in considering the lower beaches.

The most extensive of these beaches was located in the western part of the study area, stretching for 10.0 km down valley from a point near the moraine and with a width of as much as 2.0 km. In composition it proved remarkably homogeneous, consisting of grey silty sand with occasional patches of grey clay on its surface. Along the southern edge of that major area of buried beach sediments and up to 2.0 m lower than it, a smaller beach was identified (Chapter III). It is present as an almost continuous feature along the southern edge of the higher beach, the only break being caused by the buried channel of High Moss Pow. Despite the difference in size, the two features have certain basic similarities. Both are grey in colour, forming relatively level steps beneath the carse clay, the latter normally separated from them by a layer of peat. Beyond colour, form and general stratigraphy, similarities are less, but still present to a certain degree. For example, grey silty sand makes up part of the substance of both features, although the lower of the two has a surface consisting of as much as 30.0 cm of sticky, grey silt or clay, before the silty sand is encountered. With factors such as altitude and gradient (Chapter VIII), the differences become greater, leaving no doubt that there are two separate features present.

For explanatory purposes, from this point on the upper beach will be referred to as buried beach "A" and the lower as buried beach "B".

The situation existing in the west appears to be paralleled in the section between the confluence of the Goodie Water with the Forth and Blairdrummond. At two points, namely Coldoch and Woodlane, the boreholes show the presence of two buried beaches, differing slightly in altitude. Furthermore, the upper feature is composed of grey silty sand for the most part while the lower also consists of these sediments, but only beneath a surface layer of sticky, grey silt or clay. Although the altitudinal differences between the beaches were found to be slightly less at Coldoch and Woodlane than farther west -- 0.8 m compared with 2.0 m -- the textural differences are equally strong and the layer of clay on the lower beach surface is often more distinctly separated from the underlying silty sand than in the west. Completing the stratigraphy, the buried peat layer normally covering both beach surfaces in the west is also present at Coldoch and Woodlane.

In the basis of colour, composition, stratigraphy and form, the evidence for the correlation of the two pairs of beaches was thought to be strong. When altitudes were compared similarities were also apparent. In the case of beach "A", for example, west of the junction of the Goodie Water and the Forth, the lowest altitude is reached close to its eastern limit with a value of 9.0 m O.D., which compares well with 9.2 m O.D. at Coldoch, 9.4 m O.D. at Woodlane and a number of others close to the 9.0 m mark, all on grey silty sand.

Based on these factors, the grey silty sand and grey silty clay beaches between Coldoch and Woodlane are correlated respectively with beaches A and B described in the west between Menteith and Thornhill. In turn the upper, grey silty sand and the lower grey silty clay beaches between Coldoch and Woodlane will be referred to as beaches "A" and "B".

Before attempting to relate the buried beaches existing between Menteith and Blairdrummond to those east of Stirling, some discussion is required concerning the isolated patches of beach material at Sommer's Lane and Hill of Drip and the general absence of such deposits over a much larger area between Blairdrummond and Stirling. At Sommer's Lane it was not possible to locate the shoreline and as a result the heights obtained cannot be directly related to those on the major sections of beaches "A" and "B". Averaging 8.0 m O.D., however, they are close to the altitudes expected for beach "B", but the deposits do not coincide, being grey silty sand rather than grey silty clay. From its location and the adjacent stratigraphy (Chapter IV), it is considered that this buried beach section has been altered after its formation, perhaps by fluvial processes associated with the Teith gravels, and because of this, as well as its extremely limited extent it was not examined further.

At Hill of Drip, sedimentation must have been complicated by the presence of rock outcrops, channels within the rock and sands and gravel brought down by the Teith (Fig.IV.5), but the buried beach deposits that exist are quite distinct and it is apparent that the

Hill stood out as an island at the time of their deposition. The sediments are often present in two distinct layers, the upper being grey (silty) clay and the lower, grey silty sand (Boreholes, 307, 308, 312, 346 and 354), inviting comparison with beach "B" in the west. In a number of places the clay is absent and the sediments appear comparable to those of beach "A". However, it is not possible to relate the difference in texture to difference in altitude and on the basis of present evidence it is considered that the two sediment types are part of one feature. Although it has characteristics that allow it to be linked with either of the western beaches, heights of between 8.1 and 8.6 m on the Hill of Drip shoreline are at least a metre higher than those estimated from the gradient of beach "B" between Menteith and Thornhill. Mainly for this reason, it is suggested that the buried beach deposits at Hill of Drip are probably best correlated with the higher feature -- beach "A" -- in the west.

On the question of the absence of buried beach deposits over large areas between Blairdrummond and Stirling, much of the discussion of the High Buried Beach is again considered applicable here. The presence of the River Teith with its tributaries and distributaries, flowing over the outwash fan was probably sufficient to prevent the quiet conditions of sedimentation implied by the fine texture and remarkably homogeneous nature of the buried beach deposits. In this situation, the streams flowing across the relatively unconsolidated outwash must have changed course frequently leaving very little of the area outside their influence. Even where deposition of the beach sediments did take place the changing position of a stream could easily have altered the depositional environment or initiated erosion to retard the growth of the feature or destroy it. Thus, it is suggested that the absence of buried beaches between Blairdrummond and Stirling was due to unfavourable conditions of sedimentation in the first place coupled with subsequent erosion by the streams of the Teith system in the areas where deposition was possible.

East of Stirling, between Abbey Craig and Menstrie, a suite of two lower buried beaches exists along the southern margin of the High Buried Beach. At first sight these appear to be similar to the two lower beaches between Menteith and Thornhill, like them consisting of grey silty sand with grey silty clay and occupying a similar position with respect to the High Beach. However, closer investigation shows some distinct differences.

The upper, grey silty sand beach east of Stirling stands at heights between 6.6 and 7.5 m O.D., some 0.3-1.0 m lower than the High Buried Beach in the same area and appears to occupy a bench approximately 200.0 m wide cut into the southern margins of that feature (Figs.V.4 and V.5). The stratigraphy of the bench area can be represented as follows:

4. Carse clay
3. Peat
2. Grey (green) silty sand
1. Pink silty sand

Such a situation is also found in areas where the High Beach proper is present, for the top few centimetres of the deposits of that beach are commonly grey in colour, but there are certain significant differences. In the first place, the grey sediments on the High Beach are usually very thin with a maximum thickness of 20.0 cm compared with 30.0-45.0 cm for the lower feature along its southern edge. Secondly, the boundary between the grey and pink sediments on the High Beach is diffuse while in the stratigraphy outlined above the change is normally very sharp. Finally, as can be seen in Figures V.4 and V.5, there are distinct altitudinal differences between the two features. They are therefore recognised as separate entities in the sub-carse morphology of the area.

While the differences allow these features to be considered separately, they are not completely unrelated. The evidence suggests that at some time in the past the High Buried Beach occupied the whole area now shared with the adjacent grey silty sand beach. Subsequent changes in sea-level caused its outer edge to be eroded into the form of a step or bench upon which the grey silty sand was deposited. This supposition is supported by the form of the bench itself. Its inner edge is quite strongly marked suggesting erosion rather than continued deposition at a lower level and perhaps indicating erosion by a rising sea-level. At the same time, the sharp boundary between the pink and grey silty sand on the bench appears to accord with this suggestion.

One additional point requiring examination is the change from erosion of the pink silty sand to the deposition of the grey sediments. Such a situation is not uncommon in coastal geomorphology where sand or shingle can be found resting upon an abraded platform (Sparks, 1965). In that case the deposits are normally provided by the erosion of the platform and its associated cliff or by longshore drift from an adjacent area and bear some geological or textural relationship to them. In the area presently under consideration, while there is a textural similarity between the deposits, they differ in colour and source. The part played by the Old Red Sandstone rocks of the area in the development of the pink silty sand has already been noted and it has been suggested that the grey deposits have a more distant source in the Highland rocks to the west and north of the Forth valley (Chapter III). Taking all this into account, the following is advanced to explain the formation of the feature. After the development of the High Buried Raised Beach, sea-level fell somewhat, only to return later, gradually rising and eroding the outer edge of the beach until it reached an altitude of 0.3-1.0 m less than the beach surface, where conditions seem to have stabilized, causing the rate of erosion to slow down. At about the same time grey silty sand was being carried into the sea from the west (and probably with some contribution from the Devon valley), in ever increasing quantity and deposition took over from erosion as the main activity along the littoral.

The deposition of grey silty sand on the step cut in the High Beach appears to have been only the beginning of a relatively lengthy period of sedimentation in the area, for an additional terrace of the same material is present along the southern edge of that feature. With altitudes of 5.7-6.8 m O.D. it lies between 0.9 and 1.3 m lower than the adjacent composite beach, and is entirely composed of grey sediments, no pink being present even at depth. It is thought to represent an area of deposition outside the former limits of the High Buried Beach, but contiguous with it, in which sedimentation took place after a slight fall in sea-level following the laying down of the grey silty sand on the High Beach step. At its widest it exceeds

400.0 m, narrowing towards the east and ending abruptly on the south above what is presumably the buried valley of the Forth.

In composition, the beach is almost entirely grey silty sand with only occasional patches of clay on its surface and is therefore texturally very similar to the grey deposits on the next highest beach in the area. In addition, comparison can be made with the features to the west where buried beach "A" and the deeper parts of beach "B" are of similar composition. Following on from this initial development it became obvious that the comparison could be extended to cover groups of beaches. Immediately east of Abbey Craig, for example, the buried beach sequence can be outlined as follows, working from highest to lowest:

1. The High Buried Beach consisting of pink silty sand.
2. A beach composed of grey silty sand resting upon the eroded edge of the High Beach.
3. A beach composed almost entirely of grey silty sand, with surface patches of clay.

This can be compared with the group identified at Burnbank, again working from highest to lowest:

1. The High Buried Beach of pink silty sand.
2. Beach "A" consisting of grey silty sand, the upper member of a suite of two lower beaches beneath the western part of the carse.
3. Beach "B", the lower member, composed of grey silty clay resting upon grey silty sand.

Looking at these lists it is apparent that certain similarities exist, both with individual features and with the features as a group.

As described above beach number 2 at Abbey Craig has a number of characteristics such as colour, composition, form and position in the stratigraphy, in common with beach "A" at Burnbank and it is suggested that these two features can be correlated with each other. The absence of a High Beach step at Burnbank may present an initial problem. Occasionally the grey silty sand of beach "A" at Burnbank is found to have some pink coloration with depth (Boreholes 689, 693, 695 and 707), but there appears to be nothing to compare with the composite feature at Abbey Craig. This, however, does not prevent their correlation. The two areas are almost 12.0 km apart and, considering isostatic factors, it is probable that the altitudinal relationship between the High Beach and that immediately below it differs from one area to the other.

Similarly, beach number 3 at Abbey Craig may be equated with beach "B", although again slight differences do exist. The layer of grey silty clay that is characteristic of the beach surface in the west is quite patchy at Abbey Craig, grey silty sand being the predominant sediment type. This coarser deposit may be due to the provision of sandier material by the Devon and the complicity of the river is suggested at East Gogar where an isolated section of buried beach has been identified (Fig.V.8). It stands at heights between 5.8 and 6.4 m O.D. with a surface consisting of 30.0-40.0 cm of grey silty clay resting upon grey silty sand and it is regarded as part of beach number 3. As on that beach, the grey silty clay cover is not continuous and it is considered that this was brought about by the changing position of the Devon and possibly the Forth. This is supported by the presence of fluvial gravels around and beneath it as well as by former river courses cut in the carse, showing that the rivers have been capable of changing their courses in the past.

At Cambus the buried beach sediments occupy a slightly more extensive area. As described in Chapter V they consist of grey silty clay resting upon grey silty sand beneath which lies a gravel surface (Fig.V.6). The stratigraphy is well marked and with the shoreline heights between 5.3 and 5.9 m O.D., the feature is considered to represent beach number 3 in this area. Along with the sections at East Gogar and between Abbey Craig and Menstrie, the beach at Cambus has been correlated with buried beach "B" at Burnbank.

Thus, beneath the carselands east of Stirling, three buried beaches have been recognised and have been correlated with similar features at Burnbank.

This can be taken farther, however, for the sequence at Burnbank has already been related to that between Menteith and Thornhill and the High Buried Beach, east of Stirling has already been shown to correspond to that at Thornhill. It is therefore possible to consider the buried beaches in the complete study area and this can be approached by means of a relatively simple model constructed by the combination of the beaches (excluding that represented by the buried gravel layer) known to exist beneath the carse on the north side of the Forth between the Menteith Moraine and Kincardine-on-Forth.

As represented in Figure VII.3 the model can be seen to consist of three distinct and contiguous levels, the highest lying beneath the inner margins of the carse and the two others becoming successively lower towards the Forth. The highest step, designated

"High Buried Raised Beach", is characteristically composed of pink silty sand and descends at its southern edge to "Lower Buried Raised Beach A". The grey silty sand of the latter is also one of the components of the next beach in the series, namely "Lower Buried Raised Beach B". This lowest level lies to the south of beach "A" and is composed of grey silty clay overlying a grey silty sand substratum, that possibly represents the eroded edge of buried beach "A", but there is no evidence to support such a supposition. Buried beach "B" ends abruptly before the Forth is reached.

Within the study area this sequence is not always present in its entirety or exactly in the form outlined above. At Thornhill, for example, the High Beach and beach "A" are separated by the buried valley of the Goodie Water and there is no step along the outer edge of the High Beach similar to that on which beach "A" rests in the east. Again, in the stretch between Coldoch and Burnbank, the High Beach is lacking, only the lower beaches "A" and "B" being present while the almost complete absence of buried beaches above the Teith gravels and between Cambus and Kincardine-on-Forth has already been remarked upon. These discrepancies have been described in Chapters III, IV and V and while any one may seem a significant omission in one particular area, they are not inexplicable and there is sufficient overlap between areas to allow the postulated model to be regarded as indicative of the buried beach sequence in the area as a whole.

At the beginning of this section reference was made to the buried beach sequence established by Sissons (1966) in the western part of the Carse of Stirling and south of the River Forth. It now appears pertinent to re-examine that sequence and compare it with that proposed above. It has already been shown in an earlier section that Sissons' High Buried Raised Beach was the equivalent of the highest beach to the north of the Forth. In addition, the Main and Low Buried Beaches described by Sissons (1966, 1967a) and referred to in Chapter I bear a strong resemblance to those now named Lower Buried Raised Beaches "A" and "B" respectively and originally described in Chapter III at which point the similarity was first noted. It is considered that on the basis of similarities in colour, texture, form and stratigraphy described in these chapters the two sets of beaches can be regarded as the equivalent of each other and summarised as follows:-

Buried beaches according to Sissons (1966)	Buried beaches of the present survey
1. High Buried Raised Beach	1. High Buried Raised Beach
2. Main Buried Raised Beach	2. Lower Buried Raised Beach "A"
3. Low Buried Raised Beach	3. Lower Buried Raised Beach "B"

Because of the obvious relationship between the two groups as well as for convenience and continuity it is proposed to retain the original names for the lower beaches, beach "A" becoming the Main Buried Raised Beach and beach "B" becoming the Low Buried Raised Beach.

While the position of the lower beaches with respect to each other and to the higher beaches gives some indication of their relative ages it was not possible to assign absolute dates to the features. On the south side of the Forth, however, two dates have been obtained. The age of the Main Beach has been inferred from the pollen analysis of peat resting upon its surface (Newey, 1966). The base of this peat was found to correspond to the transition between Zones IV and V of the pollen sequence equivalent to an age of about

9,500 years. In the case of the Low Beach, an age of 8,800 years was estimated from a consideration of pollen analysis and radiocarbon assay. At both sites the peat immediately above the beach contained *Chenopod* pollen indicating marine conditions and implying that the peat began to grow as the sea that formed the beach retreated (Chapter I). Thus the dates obtained could be considered to give a reasonable representation of the time of formation of the beaches.

Although these dates refer to features on the south side of the Forth completely separated from those to the north and although they pertain only to the western part of the area it seems unlikely that they would differ to any great extent from those in the east or north of the river. A check has been provided by the pollen analysis of the peat resting on the Main Buried Beach beneath East Flanders Moss (Durno, 1956). The lowest metre of the peat was found to belong to Zone V of the pollen sequence dated by Godwin (1961) at about 9,550-9,000 B.P. and on the basis of the thickness of the peat Sissons and Smith (1965b) were of the opinion that the beach had been formed by the earlier part of the period dating it at 9,500 B.P. The only other date for peat overlying buried beach sediments north of the Forth is one at Littleward near Thornhill giving an age of 3,250 years (Chapter I). The beach concerned is the Low one, but either the date is in error, or the peat measured is not part of the "buried peat" as described in the present study, for it is known that by 3,250 B.P. the carse clay that overlies the Low Beach and its associated peat had already been deposited.

The Buried Valleys.

From the evidence of both shallow and commercial boreholes it is apparent that the rivers and streams of the study area formerly flowed in valleys now buried beneath the carse. These buried valleys are most obvious in the case of the larger rivers such as the Forth, the Teith and the Devon, but even medium sized streams such as the Goodie Water (Fig.III.5) and comparatively small streams such as High Moss Pow show evidence of former channels beneath the carse. In places the valley beneath the Forth exceeds a kilometre in width while even the Goodie Water channel reaches 400.0 m. The Forth channel is the principal one, stretching for the whole length of the study area, while the others are tributary to it.

All the buried valleys are characterised by, and most can be identified by, the absence of buried beach sediments, explicable either in terms of non-deposition or deposition and subsequent erosion. Of these two possibilities, the former appears more likely, for several reasons. The larger valleys such as the Forth and the Devon are only part of much deeper features, consisting of a number of glacially eroded rock basins with rockhead standing at as much as 205.0 m below sea-level. (Chapter I).

An examination of the Teith shows that its buried valley is entrenched in the sands and gravels of the Blairdrummond fan (Figs. IV.2 and IV.4). Any earlier valley must have been filled in by these outwash deposits during deglaciation following the Loch Lomond Readvance and the river eventually carved a new course through the sands and gravels. In the west, the buried valleys of the Goodie Water and High Moss Pow may have developed along similar lines with respect to the Menteith outwash. Both seem to pass out from the gap in the Menteith Moraine now occupied by the Goodie Water and it is suggested that at different times during the decay of the Menteith lobe both carried meltwater eastwards, probably aiding in the distribution of outwash in the first place but later establishing their courses by erosion. In this the Goodie Water may have been aided by water carried in by the Rednock, Tarr, and Ruskie Burns.

The stream courses in the west probably continued to develop even after the flooding in of the sea to form the buried beaches. Considering the position of the beaches at the head of a long estuary, it seems reasonable to suggest that for at least part of each day they stood above the water as mud-flats, at which time the valleys would contain streams similar to those that cross the mud-flats in the Kincardine area at present, allowing any sediments that had been deposited to be removed. No doubt the flushing action of the tides would also help in this respect. At this time the High Moss Pow was probably carrying the drainage from the Lake of Menteith, while the Goodie Water received water from the burns of the Menteith Hills. Several factors prompt this suggestion. Firstly, it is unlikely that two streams would pass through the same gap in the moraine and flow in different directions. Secondly, the upper part of the Goodie buried valley, beyond its junction with the Ruskie Burn, is filled with the sediments of the Main Beach. Thirdly, if the drainage of the Lake of Menteith had flowed out via the Goodie Water, it would have deprived the High Moss Pow and allowed it to be filled, to some extent at least, with buried beach sediments.

As the sea-levels rose and fell during the formation of the buried beaches, the smaller channels probably changed from tidal creeks to river valleys and back again, while the larger features such as that of the Forth remained estuarine, the main change being in extent. The latest date at which the sea was confined to the buried valley of the Forth has been estimated by Sissons (1966). From the age of the Low Buried Beach it was known that the sea-level had fallen below it by 8,800 B.P. and by dating the peat on the beach surface where it merged with the overlying carse-clay it was possible to calculate the date by which the sea had risen again to flood over the peat. The date obtained was 8,270±160 B.P. and, allowing time for the rise to take place, it was estimated that minimal sea-level was reached in the buried valley close to 8,500 years ago.

From that time the sea-level began to rise, gradually submerging the buried beaches. The approach of the sea can be identified in the buried peat layers by an increase in *Gramineae* and *Chenopodiaceae* pollen as the junction with the carse-clay is approached. At two places in the west the rate of growth of the peat linked with continued isostatic uplift enabled it to maintain itself above the rising carse sea producing two areas of non-deposition of carse-clay (Sissons and Smith, 1965b). In most places, however, the submergence was complete, reaching a maximum by 5,500 B.P., causing the burying of the beaches and the infilling of the valleys by carse-clay. The persistence of the valleys during the formation of the buried beaches and their later filling with the deposition of the carse-clay may be explained by the different amounts of submergence involved. The carse sea stood considerably higher than those that formed the buried beaches. As a result, the valleys must have been for the most part below low tide mark at the maximum of the carse sea and therefore did not undergo the flushing action they had experienced previously. In addition all of the buried beaches were formed within a 1,500 year period and sea-level fluctuated considerably during that time. On the other hand submergence by the carse sea was much more uniform and lasted for approximately twice as long allowing greater and more extensive sedimentation. Even after this, however, there was probably some surface manifestation of the buried valleys for the present stream courses often follow the general lines of these former valleys.

Summary of Events.

1. Following the Perth Readvance of some 13,000 years ago sea-level fell by stages reaching a low slightly below the present level by 11,800 B.P.
2. A rise from this low level accompanied by erosion of Lateglacial marine sediments, till and rock produced the buried gravel layer.
3. The continuing rise reached 10.0 m O.D. sometime during the halt of the Loch Lomond Readvance ice at the Menteith Moraine.
4. With the decay of the ice outwash was carried into the head of the Forth valley. At the same time sand and gravel was being laid down in the form of fans all along the northern edge of the Forth basin, particularly at Blairdrummond and along the face of the Ochil Hills.
5. Within a very short period close to 10,300 B.P., after the main deposition of the outwash but before the complete decay of the ice the High Buried Raised Beach was formed.
6. After a short period of low sea-level, a rise allowed the

development of the Main Buried Raised Beach dated at 9,500 B.P.

7. An additional fluctuation of a fall in sea-level followed by a rise produced the Low Buried Raised Beach along the southern margin of the Main Beach. This was completed by 8,800 B.P.
8. A final lowering caused the sea to be confined to a relatively narrow estuary by 8,500 B.P.
9. The subsequent submergence beginning shortly after that and reaching a maximum by 5,500 B.P. caused the earlier beaches to be buried beneath the layer of carse-clay that forms the present surface.

CHAPTER VIII

THE ALTITUDES AND GRADIENTS OF THE BURIED BEACHES

Much of the early work on Scottish raised beaches stressed altitudinal relationships, particularly with reference to the supposed 25, 50 and 100 foot levels, and correlations were made over considerable distances based on altitude alone, on the premise that the features were horizontal. More recently, however, investigators have examined the relationship between the beaches and the isostatic recovery that followed the last glaciation, emphasising the sloping, rather than horizontal shorelines produced by differential uplift (Chapter I). The amount of uplift involved has been shown to depend on two factors; the position of the beach with respect to the area of maximum isostatic compensation and the period of formation of the feature.

Until quite recently, the sloping nature of shorelines in estuarine locations, such as the Forth, was linked to the increasing effects of tidal range towards the head of the estuary. While this undoubtedly does play a part in causing shoreline tilting it is normally considered to be extremely limited when compared with isostatic rebound. Using evidence from the present shoreline in the Forth, Smith (1968) has shown that the greater part of the differential elevation of the carselands is due to isostatic effects and since the present study is concerned with the same general area, his findings have been applied to the shorelines of the buried beaches.

In Scotland, the centre of isostatic recovery is considered to lie in the south-western Grampian Highlands (Donner, 1959) and outwards from that area the amount of uplift diminishes, the maximum decline taking place along a line drawn at right angles to the isobases. Figure VIII.1 shows isobases drawn for the Main Postglacial Raised Beach, for which the greatest quantity of altitudinal information is available, and it can be seen that the line of the Forth valley cuts the isobases at a high angle. While these isobases apply to only one period of time, it is considered unlikely that the basic pattern would differ markedly for other periods and it would be expected that other beaches would be similarly affected by increased uplift towards the west causing the surface to slope up in that direction. Such slopes have been demonstrated for a number of raised beaches in the Forth valley (Chapter I) and it would appear to be in order to infer a similar condition for the buried beaches.

As pointed out above, a second factor influencing the slope of raised beaches is the age of the features. This is based on the fact that older beaches have been experiencing uplift for a longer period of time than their more recent counterparts while it has also been shown that uplift has not always been constant. The greatest rate of uplift appears to have been achieved relatively soon after the decay of the ice and has since slowed considerably (Flint, 1957; Sissons, 1967a). For the Gulf of Bothnia, for example, Gutenberg (1941) has estimated that the present rate of uplift is only about two-thirds the average maintained during the last 7,000 years while for the Stirling area in the Forth valley, Sissons (1962) has

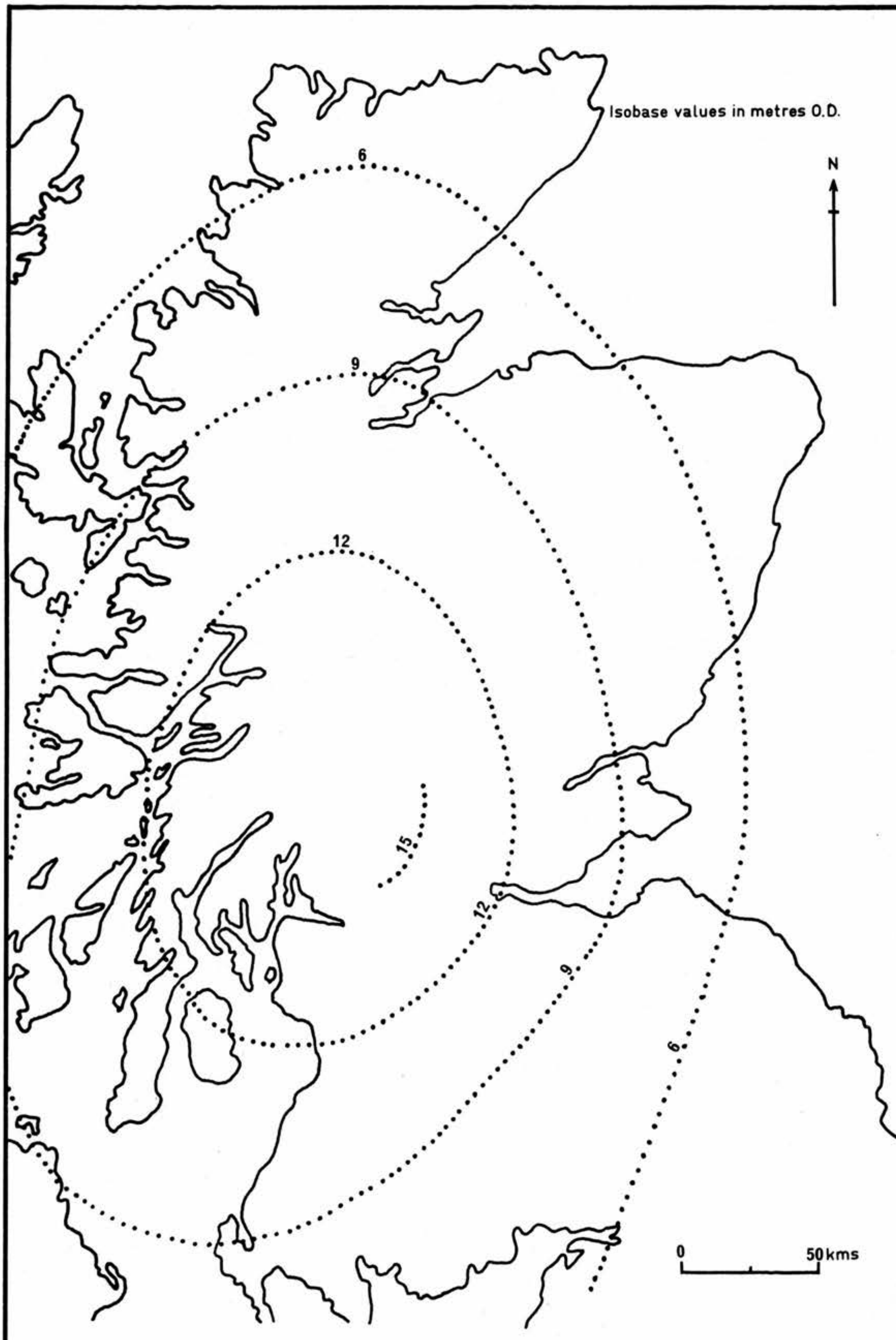


Figure VIII.1 Isobases for the Main Postglacial Shoreline

(After Sissons, 1967a.)

estimated that in the 5,000 years prior to the formation of the Main Postglacial Raised Beach uplift was taking place at a rate of almost 0.9 m per century compared with a rate of slightly less than 0.15 m per century since then. The net result is that the older beaches should have considerably steeper gradients than those formed more recently and this pattern appears to be present in the Forth. The oldest Lateglacial shorelines identified in East Fife have slopes of as much as 1.26 m/km, which compares with 0.43 m/km for the Main Perth shoreline and 0.08 m/km for the Main Postglacial shoreline (Cullingford and Smith, 1966; Sissons, 1967a). Using a broad scale and considering well marked and measured features, relative gradients can be postulated for the buried raised beaches as a group. Found within the Perth Readvance limits they must be younger than the beaches associated with that event while at the same time they are buried by the deposits of the Main Postglacial submergence. On this basis measurements along the shorelines of the buried beaches might be expected to produce gradients somewhere between that of the Main Perth shoreline and that of the Main Postglacial shoreline.

For the calculation of the gradients, height-distance diagrams and linear regression equations were developed for each buried beach, or in some cases for sections of each beach. Heights measured along the shoreline were projected on to a plane drawn through the Forth valley and aligned N72°W - S72°E; this line being chosen since it is thought to be the one most nearly at right angles to the isobases as known at present (Sissons, Smith and Cullingford, 1966). Distances from a point close to the western end of each beach were measured from the line and against these, shoreline heights were plotted in height-distance diagrams. (Figure VIII.2, for example, shows all projected heights between Menteith and Cambus.) The values of height and distance were then compared statistically and from the results regression lines and gradients were obtained.

The High Buried Raised Beach.

The High Buried Beach is present between the Menteith Moraine and Thornhill, at Burnbank and between Abbey Craig and Menstrie. These three areas are distinctly separate from each other and because of the distances involved (Fig.VIII.2) it was not considered feasible to draw one regression line incorporating all three sets of data, although, if the three sections are part of the same feature, as is strongly suggested by the stratigraphy and the other elements mentioned, it would be expected that the individual lines would have the same or at least similar gradients. To investigate this 17 measurements from the Menteith-Thornhill area, 10 from Burnbank and 12 from the area east of Stirling were treated as outlined above.

From the initial height-distance diagrams (Figs.VIII.3 and VIII.4) it would seem that there is a definite slope in the western section while at Burnbank and east of Stirling the features vary little from the horizontal. To check this, a series of correlation coefficient tests were carried out. In the Thornhill area the data produced a coefficient of -0.360 while south of the Ochils between Abbey Craig and Menstrie the figure was -0.094. The negative results indicate one variable increasing in value as the other decreases, or specifically, as distance from the point of origin increases the shoreline height decreases, as might be expected from the normal slope of Lateglacial beaches down the Forth valley.

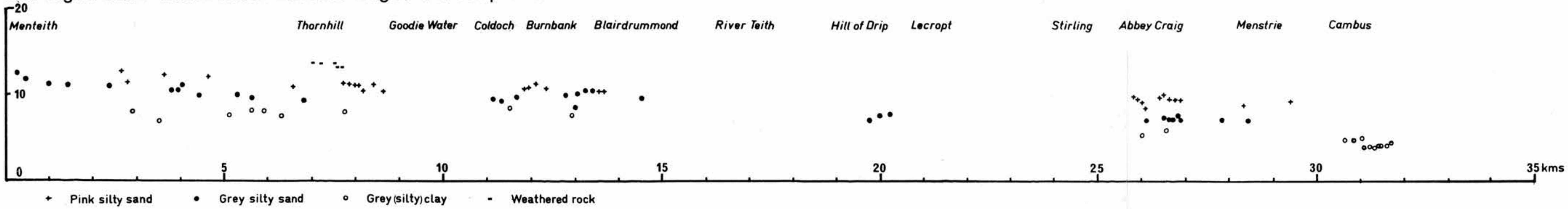


Figure VIII.2 Buried Beach shoreline heights and composition

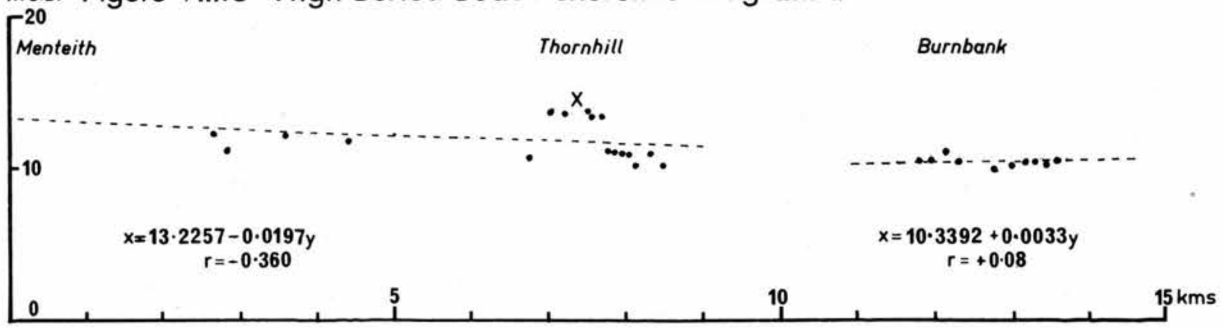


Figure VIII.3 High Buried Beach shoreline diagram 1.

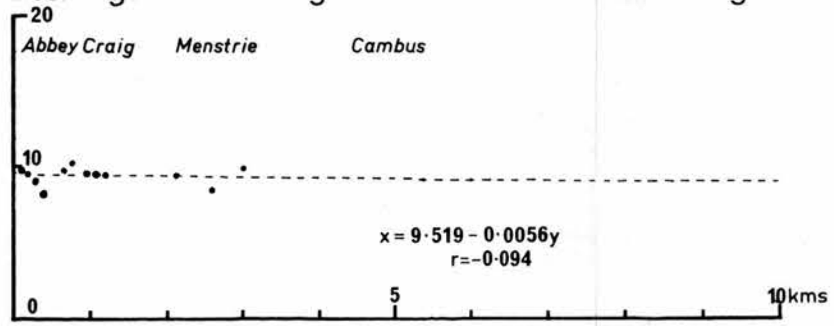


Figure VIII.4 High Buried Beach shoreline diagram 2.

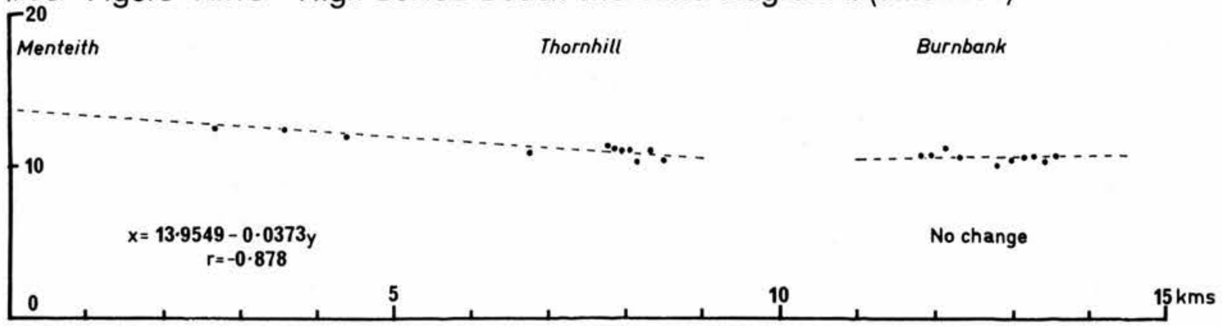


Figure VIII.5 High Buried Beach shoreline diagram 1. (amended)

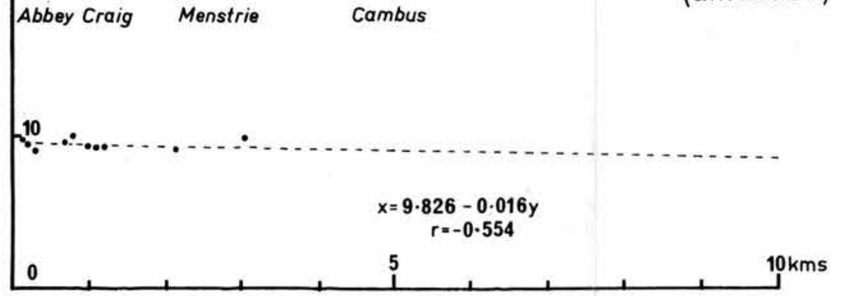


Figure VIII.6 High Buried Beach shoreline diagram 2. (amended)

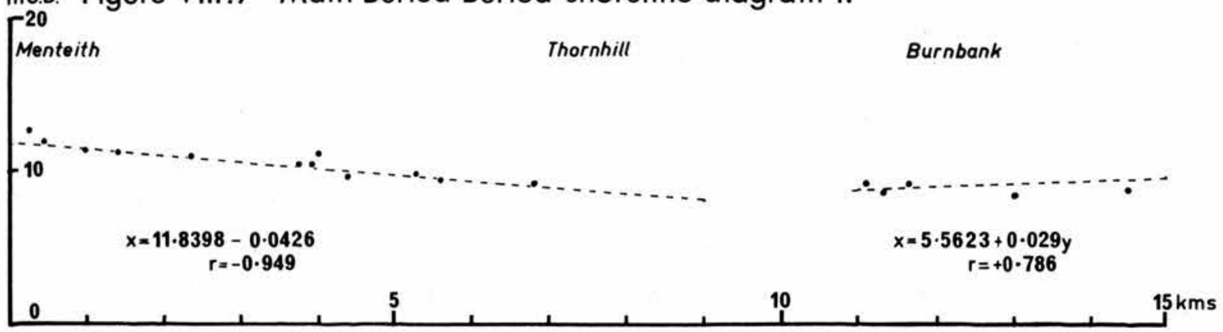


Figure VIII.7 Main Buried Buried shoreline diagram 1.

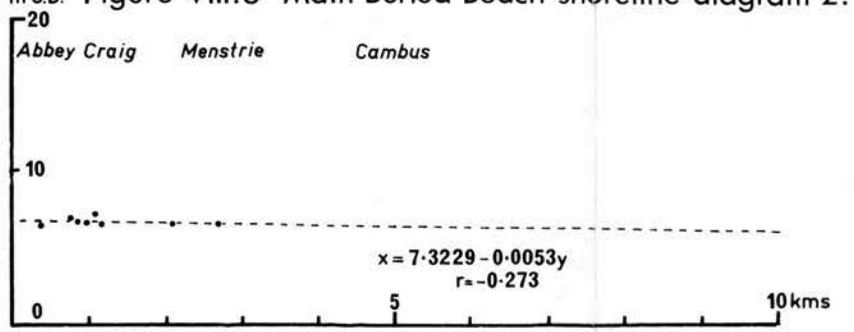


Figure VIII.8 Main Buried Beach shoreline diagram 2.

The third section of beach at Burnbank was found to differ from the other two in that the ten heights in that location showed a positive correlation indicating a rising shoreline downvalley. As was the case east of Stirling, the correlation coefficient was very low, being only +0.078. Such low values were thought to be to a large extent a result of the lack of slope apparent in the height-distance diagrams and regression lines and gradients were determined to examine this further.

For the High Beach in the Thornhill area, a slope of 0.197 m/km was calculated while the corresponding figure for the feature east of Stirling was 0.056 m/km, both slopes being in a downvalley direction. At Burnbank, with the slope in the opposite direction, the figure was 0.033 m/km. Taking the three together, the value at Thornhill is markedly different from the other two, but does fall within the range postulated, being less than half of the slope of the Main Perth shoreline yet remaining greater than that of the Main Postglacial shoreline. On the other hand, while at Burnbank the slope is up to the east and between Abbey Craig and Menstrie it is down in the same direction, an essential fact is that at both locations the beach is not far removed from the horizontal. Thus, it is apparent that the three sections do not completely fit the pattern noted above where all three would have the same or similar gradients.

A fact that cannot be overlooked is the possibility that features of entirely different age are being compared. It is considered, however, that the evidence presented concerning stratigraphy, form and composition is sufficiently strong to outweigh the gradient differences and support their correlation. This being so, the difference in values may be partly explained by slightly different depositional environments in the two areas and in order to examine this some consideration must be given to the formation of the High Buried Beach, for it is felt that this may have some bearing on the results obtained. From an examination of the High Beach on the south side of the Forth, it has been shown that its final formation took place in a relatively short period after the deposition of the main Menteith outwash, but before the ice had finally left the moraine (Chapter I). Although the evidence on the north side of the river does not allow the same precision, it does support a formation at the same time.

The sediments of which the beach is composed were probably provided to a large extent by meltwater streams flowing out from the decaying ice. However, from the colour of the beach, it would seem that a considerable proportion of the material was obtained from the adjacent Old Red Sandstone sediments (and from accompanying volcanics in the case of the Ochils) that must have backed the coastline at the period of formation. Agencies such as marine erosion and deposition from streams flowing into the sea must have provided sediments for the building of the beach, but a further important factor, particularly along the Ochils, may well have been slope wash or slumpage from the slopes behind the beach. The amelioration of climate after the glacial period would provide suitable conditions and this process has already been used to explain the hummocky nature of the High Buried Beach near its backslope (Chapters III and V). If this was so, it would have certain implications as far as the above results were concerned. Firstly, with streams and mass movement providing an abundance of material for the formation of the beach, the relative importance of the sea in determining the form of the shoreline may have been reduced and the net effect of isostatic recovery hidden somewhat. Secondly, the hummocky nature of the beach near its inner edge would make the choice of heighting points very important (Chapter V). Where a beach is visible, some allowance can be made, but the difficulties are increased if it is buried, as is the case with the High Beach.

With differences in gradient such as those existing between the Menteith-Thornhill section on the one hand and the Burnbank and Abbey Craig-Menstrie sections on the other, together with the limited number of heights available, it was thought unlikely that a revision of the points would radically alter the pattern. Nevertheless, the borehole logs and beach profiles were re-examined in an attempt to minimise the possibility of misrepresentation. Where any doubt existed as to the position of a particular spot-height with reference to the shoreline, it was discarded.

The main problem concerned 5 heights (marked X in Figure VIII.3) referring to the sub-carse surface near Thornhill at approximately 13.0 m O.D. The surface consisted of weathered rock or coarse red sand resting upon rock and in the short distance over which it was located it was virtually horizontal. While it could not be linked with any other feature in the area it was not considered to belong to the High Beach. Three additional heights, one near Menteith and two east of Stirling appeared non-representative and were therefore removed from subsequent calculations.

This brought about the reduction of heights to 11 between Menteith and Thornhill and 10 east of Stirling, the number at Burnbank remaining the same. The amended groupings were then replotted on height-distance diagrams (Figs.VIII.5 and VIII.6) and in both cases the general downvalley slope was apparent. In the west, the revision produced a much stronger correlation coefficient at -0.878 and the regression line calculated from it gave a gradient of 0.373 m/km, slightly less than double the original figure. Between Abbey Craig and Menstrie, the correlation was also improved, to a value of -0.554, while the gradient increased to 0.168 m/km from 0.056 m/km, reducing its similarity to the slope of the Burnbank section. These results along with the figures from Burnbank were considered to be the best obtainable from the available data and were used in interpretation and for comparison with results from other buried beaches.

In summary, it can be noted that the High Buried Raised Beach on the northern side of the Forth valley does not exist as a feature with a single gradient applicable to its entire length. It has been shown to consist of at least three sections with different gradients (Fig.VIII.9). The slope is greatest in the west between Menteith and Thornhill where it falls from 12.8 m O.D. near the former to slightly less than 11.0 m O.D. just east of the latter. Beyond the break in the beach at Coldoch, heights close to the lower value are also found in the almost horizontal section at Burnbank. Such a situation suggests that a sharp change in gradient takes place somewhere in the vicinity of Thornhill, the pronounced eastward slope being replaced by one lying close to the horizontal. Downvalley from Burnbank the High Beach is absent as far as Abbey Craig, but the height difference between the two sections allows a gradient to be estimated. Over a distance of 12.0 km the height of the shoreline is reduced by approximately one metre, giving a slope of 0.08 m/km. This compares closely with the slope for the Burnbank area in that both are very low and over the distance between Thornhill and Abbey Craig the slope of the beach is considered to differ little from the horizontal. Beyond Abbey Craig the gradient increases again, but does not approach the value for the section west of Thornhill.

Part of the reason for the changing gradients may involve a variation in depositional environments as has already been suggested with mass movement and sediments from the Devon valley playing a greater part in beach formation along the Ochils than farther west. The same might apply at Burnbank with material being carried into an embayment in the shoreline by the Burnbank Burn. In addition, the possibility of different amounts of uplift in different areas cannot be ignored and with regard to this it can be pointed out that Smith (1968) noted a slight reversal of the gradient of his Postglacial 1 shoreline in the Burnbank area. At this stage, the amount and distribution of heights on the High Beach limits the conclusions that can be drawn, but it appears that the situation is more complicated than at first anticipated and will be considered further when the gradients of the other beaches have been examined.

The Main Buried Raised Beach.

The Main Beach is commonly found lying to the south of the High Beach. For a short stretch at Coldoch, however, the latter is absent and in the Thornhill area the two features are kept apart by the buried valley of the Goodie Water. The most extensive section of the beach is in the west between Menteith and Thornhill with smaller patches at Coldoch-Blairdrummond and east of Stirling between Abbey Craig and Menstrie. In addition an isolated section encircles the rock outcrop of the Hill of Drip.

Shoreline heights from each of these places were examined initially in Figure VIII.2 and by inspection it was apparent that quite marked differences in gradient existed from section to section. In the west, for example, near Menteith there are several points standing in excess of 11.0 m O.D. the highest being 12.1 m O.D. while 7.0 km to the east at Thornhill the lowest altitude is 9.0 m O.D., giving an overall height difference of 3.1 m and indicating a considerable eastward slope. In contrast, between Coldoch and Blair-drummond the altitudinal difference is 1.3 m and it is evident that the surface is sloping in the opposite direction, while in the Abbey Craig-Menstrie area the heights fall into the range 6.6-7.5 m O.D., the shoreline being close to the horizontal. To examine these factors in more detail, the groups of heights were subjected to correlation tests and regression lines were drawn using the techniques already outlined.

For the longest section of Main Beach, west of Thornhill, a total of 12 shoreline heights gave a strong correlation coefficient of -0.949, indicating a downvalley slope. The gradient calculated from this figure was 0.426 m/km (Fig.VIII.7) which does not quite fit the broad pattern noted above since it is the same value as that indicated for the Main Perth shoreline, a considerably older feature, and exceeds that of the High Buried Beach in the same area. With regard to this result, it must be pointed out that over a distance of approximately 4.0 km the Main Beach shoreline has been replaced by the buried valley of the Goodie Water and it was necessary to estimate its height using the general surface level of the beach south of the valley as a guide, projecting it across the valley until it intersected the edge of the High Beach, at which point the height was taken. It is considered that the altitudes produced were reasonable estimations since the surface of the beach departs little from the horizontal in a north-south direction and any slope that does exist is regular (Figs.III.4 and III.5). Five heights were estimated in this way, all towards the eastern end of the feature and despite the precautions taken, any under-estimation of these heights would have the effect of increasing the overall gradient. Nonetheless, while this may allow that particular value of the gradient to be questioned, inspection of the seven western heights on the Main Beach shoreline proper (Fig.VIII.2) indicates that its considerable slope cannot be denied.

The steep slope of the western section ends at Thornhill and from Coldoch to Blairdrummond the shoreline rises at a rate of 0.299 m/km. With only five poorly distributed heights available, however, the significance of this figure is questionable, although it does compare with the slope of the High Beach in the same area, in direction if not in value. The number and location of the heights may partly explain the anomaly and the most easterly two of the five are at points where the beach overlaps the Burnbank and Blairdrummond gravels which may have caused some increase in height. Whatever the cause, it is clear from the more general altitudinal information on the Main Buried Beach that the section between Coldoch and

Blairdrummond must be considered as a separate entity as far as shoreline gradient is concerned.

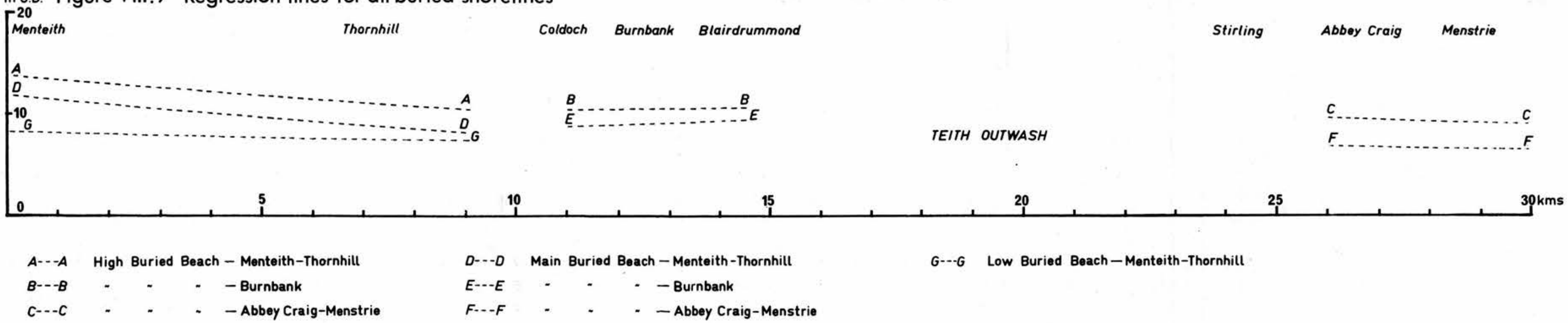
In the other major portion of the Main Beach, east of Stirling, nine measurements along the shoreline gave a height-distance correlation coefficient of +0.298 rather limited in its statistical significance and indicating a rise in altitude of the feature eastwards at a rate of 0.100 m/km. Initially, the depositional activities of the River Devon were seen as a possible reason for this anomalous slope, the addition of material to the eastern end of the beach being sufficiently great to mask the effects of later isostatic uplift. Further examination of the altitudinal data, however, cast doubt on the validity of the first number in the group. At 6.6 m O.D. it was at least 0.4 m lower than any other height and being at the western end of the system might in itself have been responsible for the calculated rise towards the east. To test this a new correlation coefficient was obtained using the eight remaining heights and this gave a value of -0.273, still very low, but indicating an eastward gradient, which was calculated at 0.053 m/km (Fig.VIII.8). With the altitudes involved all falling within 0.5 m of each other and with the second gradient much closer to the situation indicated in Figure VIII.2, it was considered that the result obtained using eight heights was more representative than that produced by the original nine.

Reviewing the information presented above, it is apparent that the steeply sloping shoreline of the section of Main Beach downvalley from Menteith is replaced at Thornhill by a stretch that slopes upwards as far as Blairdrummond where the beach ends against the Teith gravels. Where the shoreline can be identified again east of Stirling, it is found to slope gently eastwards. As was done with the High Beach, an estimation of a gradient can be made to link the sections east and west of the Teith gravels. At Blairdrummond the shoreline averages close to 9.0 m O.D. compared with an average height of slightly more than 7.0 m O.D. between Abbey Craig and Menstrie. Since the distance involved is more than 11.0 km the gradient is approximately 0.18 m/km. With the High Beach it was possible to show that the gradient of the section in the Burnbank area could be considered along with that estimated between Blairdrummond and Stirling since both were close to the horizontal. This is not immediately possible in the case of the Main Beach because of the relatively steep downvalley rise between Coldoch and Blairdrummond. However, some doubt has already been cast on the validity of that result and it is further weakened if the gradient between Thornhill and Abbey Craig is examined. At the former, shoreline heights are very close to those for the Burnbank area and their comparison with heights on the eastern section at Abbey Craig allows a gradient of approximately 0.12 m/km to be estimated. Since this figure is similar to that for the shorter distance between Blairdrummond and Abbey Craig, it is suggested that the result for the Coldoch-Burnbank area is in error, although the possibility of a slight up-gradient to the east cannot be completely ruled out.

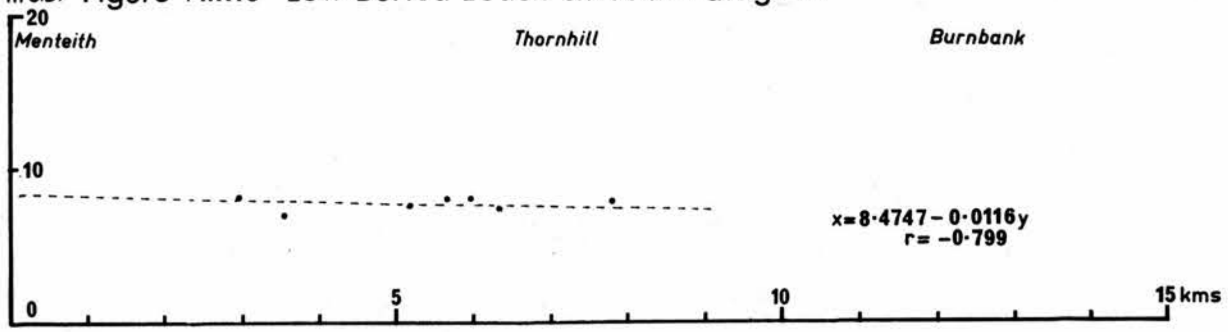
Some additional modification is allowed by three heights on the Main Beach shoreline at the Hill of Drip. At slightly greater than 7.0 m O.D. they are extremely close to the heights available east of Stirling, indicating that between Hill of Drip and the eastern section of the beach, the shoreline is virtually horizontal at a gradient close to 0.03 m/km. As a corollary to this, a change in level must take place between Blairdrummond and Hill of Drip, but unfortunately, with the presence of the Teith gravels and the probable effects of their deposition on beach formation, it has not been possible to locate the changeover more precisely.

To summarize, it is suggested that from Thornhill to a point between Blairdrummond and the Hill of Drip, the shoreline of the Main Buried Beach lies close to 9.0 m O.D., perhaps rising slightly towards the east. Beyond this, through the Hill of Drip to the Abbey Craig-Menstrie area the beach stands at little more than 7.0 m O.D. with only a slight increase in gradient east of Abbey Craig. Thus, between Thornhill and Menstrie, while the shoreline in general lies close to the horizontal, there are noticeable changes in altitude from area to area.

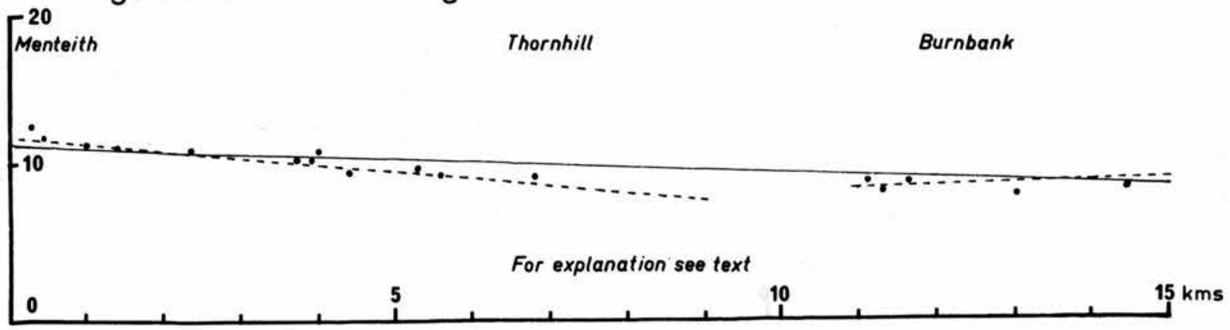
At this stage it is perhaps apparent that there is a certain similarity between the shoreline gradients of the High and Main Buried Beaches in both the overall pattern and in individual sections (Fig. VIII.9). In the west, the shorelines slope relatively steeply down-valley as far as Thornhill where they reach heights close to those measured at Coldoch and Burnbank, indicating a sharp change in gradient that is common to both beaches. From Thornhill eastwards to Abbey Craig the slope of each beach is relatively gentle with a slight reversal of gradient at Coldoch and Burnbank persisting as far as Blairdrummond. Beyond Abbey Craig the gradients increase again, that of the High Beach moreso than that of the Main Beach. The overall relationship appears strong and it is suggested that the separation of the Main Beach into two facets between Thornhill and Abbey Craig m O.D. Figure VIII.9 Regression lines for all buried shorelines



m O.D. Figure VIII.10 Low Buried Beach shoreline diagram



m O.D. Figure VIII.11 Possible regression lines for the Main Buried Beach



will also apply to the High Beach, although it cannot be proved from the information available at present.

Having outlined the close relationship between the slopes of the High and Main Beaches, the case of the Low Beach can now be examined. Although the information here is relatively slight, it might be expected that it would bear some similarity to the higher features. The only area with data adequate for the calculation of a correlation coefficient and regression line is west of Thornhill, where seven heights are available (Fig.VIII.10). These produced a relatively strong correlation coefficient of -0.799 which in turn gave a gradient of 0.116 m/km. With its slope to the east this compares with the two higher shorelines in the area although the actual gradient is much less. Beyond Thornhill at Coldoch and Burnbank two heights stand slightly higher than those of the more westerly group and this might be an indication of the slight rise noted in this area in the other shorelines. East of Stirling the 12 heights that have been measured on the Low Beach shoreline are not sufficiently well distributed to allow any accurate calculation of gradient to be made, although they do suggest that the beach slopes relatively steeply between Abbey Craig and its most easterly location at Cambus. While the gradient of as much as 0.20 m/km estimated for this stretch is considered rather high it may well be indicative of the increase in gradient noted for both the High and Main Beach shorelines in this area. (Since mining subsidence is prevalent in this area, the possibility of it increasing the slope of the Low Beach was considered, but examination showed no evidence that it was of any importance in this particular case.) Because of the limited data it is not possible to elaborate further on the relationship of the Low Beach to the higher pair, but considering the broad similarity that applies to other aspects of the beaches, it is suggested that the distribution of gradients along the Low Beach should not differ radically from that of the other two.

Gradients for the equivalent buried beaches on the south side of the Forth have been calculated or estimated by Sissons (1966, 1967a) and these can now be compared with results from the present study. Sissons found the High Beach in the west to be close to the horizontal while the same feature north of the Forth slopes to the east at a rate of 0.373 m/km. The lack of slope in the south was initially explained by the effects of stream deposition along the shoreline, masking the effects of isostatic tilting. However, numerous streams carry material off the hills behind the carse on the north side also, yet the shoreline gradient is considerable. This does not necessarily disprove the importance of stream action, but it does suggest that it might not have been the sole reason for the relative horizontality of the High Beach south of the Forth. A second estimation for the beach as a whole from Menteith as far as Grangemouth produced a gradient of about 0.2 m/km.

Sissons also calculated a slope of 0.15 m/km for the Main Beach and slightly less for the Low Beach. With a gradient of 0.116 m/km the Low Beach between Menteith and Thornhill fits the pattern, but at 0.426 m/km the slope of the Main Beach shoreline in the same location is almost three times as great as that of its southern counterpart. Attention has already been drawn to the questionable accuracy of such a large value -- it is in fact equal to the gradient calculated for the Main Perth shoreline in the Forth -- but even allowing this, the figures for the High and Low Beaches suggest that a more accurate value would still be greater than 0.15 m/km. Thus, with the exception of the similarity between the Low Beach sections, there appears to be little relationship between the shoreline gradients of the buried beaches on either side of the Forth valley in the west.

One of the main problems in comparing shoreline gradients involves the examination of like features. For example, in the past it has been common to look at shorelines as features with a single gradient continuous over their whole length. The present study has indicated that the buried beaches at least do not conform to this system, but consist of a number of facets along their length, each with a distinctly different gradient. Taking the section of the Main Beach between Menteith and Burnbank as an example, the overall gradient is 0.167 m/km. On dividing the shoreline in two, in keeping with evidence from the height-distance diagram (Fig.VIII.11), the western section gives a gradient of 0.426 m/km while the eastern rises downvalley at a rate of 0.299 m/km, both values markedly different from each other and from the original. It is not valid therefore to compare the gradient of a small section of shoreline with that of the complete feature. This may apply to the comparisons attempted above, for the results produced on the south side of the Forth were obtained between Menteith and Stirling and perhaps represent an average of two or three gradients. Since the buried beaches show the presence of sections with distinctly different gradients along their length, it is possible that other older or younger beaches in the area will do the same and until the presence or absence of such sections can be verified the gradients are not strictly comparable.

While the presence of changing gradients can be recognised relatively easily by inspection, the reasons for their presence are less easily arrived at. It was suggested above that on the High Beach shoreline the reversal of gradient at Burnbank and the relatively low value along the face of the Ochils might be due to depositional conditions along the shore when the beach was being formed, with the abundance of streams and mass-movement carrying sediments into the sea helping to mask the effects of isostasy. It is certain that this type of deposition took place, but its importance in influencing the gradient has to be re-examined in the light of evidence from the Main Beach. The changes in gradient along the shoreline of this beach closely parallel those of the High Beach, while the latter itself normally separates the Main Beach from the source of extra depositional material in the Ochils or the hills behind the carse. This being so it would seem necessary to look for a more fundamental cause. Since the tilting of the shoreline is caused in the first place by isostatic compensation, it is possible that local differences in uplift would produce the variations. This is supported to a certain extent by the Postglacial beaches. For example, Smith (1968) has noted a reversal of gradient in his Postglacial I shoreline at Burnbank, the same area in which the High and Main Beach shorelines rise downvalley, while well away from any peculiarities that the Forth valley might possess, McCann (1966) has pointed out differential tilting of the Main Postglacial shoreline near Loch Linnhe in Western Scotland. At this stage it is not possible to speculate on the reasons for local changes in the amount of uplift, but it is suggested that a closer investigation of the geology or glacial and depositional history of the Thornhill-Burnbank-Blairdrummond area, where the changes are most obvious, might provide some of the initial answers.

CHAPTER IX

RELATIONSHIPS BETWEEN THE BURIED BEACHES AND FEATURES OR EVENTS BEYOND THE FORTH VALLEY

The buried raised beaches and associated landforms have little surface expression at the present time, yet it has been shown that they are major features in the geomorphological development of the Forth valley. Together they underlie more than 50 sq km of the carse-lands and represent some 3,500 years of depositional and erosional activity before their burial beneath several metres of carse-clay during the Postglacial transgression.

The study of the buried beaches has revealed considerable oscillations of sea-level during the period of their formation and this provides a point from which some wider relationships may be examined. It is generally accepted that during the last several thousand years world sea-level has varied largely as a result of the after effects of the last major glacial period, the level rising as water, previously trapped on land in the form of ice, melted and returned to the ocean or falling when land ice periodically reasserted itself. Expressed in these terms, no account is taken of local variations that might alter that simple relationship and it is suggested that an examination of the situation in the Forth and its comparison with the overall pattern might allow some estimate to be made of the extent and importance of local conditions on sea-level change in this particular case.

In addition, the buried beaches of the Forth are part of a distinct stratigraphical sequence that includes the carse-clay of the Postglacial transgression and if features comparable to the buried beaches are present elsewhere in Scotland a probable location would be in association with the carse-clay. While the latter has been examined by numerous workers since the second half of the 19th century (Chapter I), information on the sub-carse deposits remains extremely limited, restricting any comparisons that might be attempted from area to area. However, the evidence from areas of carse-clay outside the Forth has been considered below and possibilities for further investigation have been outlined.

Sea-level change.

The multiplicity of articles that have risen out of the widespread evidence of sea-level change often possess an exactitude that is more apparent than real. Part of the problem rests with the initial evidence, for despite its extent it is often in a form unsuitable for interpretation or quantification, but the nature of the change itself poses even greater difficulties. Total sea-level change depends upon several factors working together in such an integrated fashion that individual effects cannot be readily separated from the whole, while the relative importance of the various components changes with location and with time. These components fall into two groups, namely, those causing upwarping or downwarping of land and those producing eustatic changes of sea-level. In the former may be included the deformation of coastal areas by tectonic downwarping as in the case of the Netherlands and Southern England, the change in isostatic balance produced by large scale erosion of the landscape and redistribution of sediments, and glacio-isostatic movements. The latter include changes in the form of ocean basins, the displacement of water by sediments, changes in volume of sea-water with changing temperature and variation in the amount of water retained on land in glaciers and ice-sheets (West, 1968). Most of these factors are difficult to quantify with any great accuracy, but it is often possible to estimate their relative importance in time and place. During the period and in the area with which the present study is concerned for example, it is normally considered that the most important element in determining the relative level of land and sea has been the combined effect of the eustatic and isostatic movements produced by glaciation (Walton, 1966). The separation of these two components is not without problems, but by comparing the varying positions of land and sea in the Forth valley with calculated world-wide eustatic changes it should be possible to estimate the relative importance of the isostatic and eustatic elements in the formation of the buried beaches.

Various workers in recent years have been concerned with eustatic movements in specific areas or in the world as a whole (Bennema, 1954; Shepard and Suess, 1956; Godwin, Suggate and Willis, 1958; Curray, 1965; Segota, 1968) and their results have been summarised by Jelgersma (1966) and Guilcher (1969). Despite the fact that many of these researchers have used similar methods and have considered results from the same areas, there is little overall agreement on recent changes in sea-level and Jelgersma (1966) has noted that it may never be possible to construct a good curve of eustatic changes during the Postglacial period. Major problems arise from the quantity and quality of the data and from individual interpretation of the various factors influencing sea-level change. In most cases, for example, radio-carbon dates from deposits overwhelmed by the rising sea have been utilized in the production of a curve, but the fact that few of the dates have been obtained with sea-level change as a specific objective has caused difficulties in interpretation. Furthermore, in order to isolate eustatic changes in level from isostatic and tectonic influences the dates must pertain to areas of relative stability in the earth's crust. Fairbridge (1961) attempted to satisfy this requirement in drawing up his curve, but others such as Shepard and Suess (1956), Godwin, Suggate and Willis (1958) and Segota (1968) used dates obtained from such areas as the Mississippi delta and the Netherlands where local tectonic movements or the compaction of sediments must surely affect the final results. While some allowance can be and has been made to compensate for the non-eustatic variations, there remains less likelihood of error if results from stable areas are used where possible. However, as Jelgersma (1966) has pointed out, "even then the results are questionable since it is hard to believe in the stability of any area of the world".

Considering these points, it must be apparent that there may be considerable imprecision in most (if not all) curves of eustatic change and this may account for the variety of positions and forms of the curves reproduced in Figure IX.1. Contrasting with this is the relative accuracy possible when considering isostatic changes which may be obtained from the results of accurate levelling. In combining the two factors - isostasy and eustasy - in order to relate local variations in sea-level to the world-wide pattern, much will depend upon the choice of eustatic curve. That produced by Fairbridge (1961)

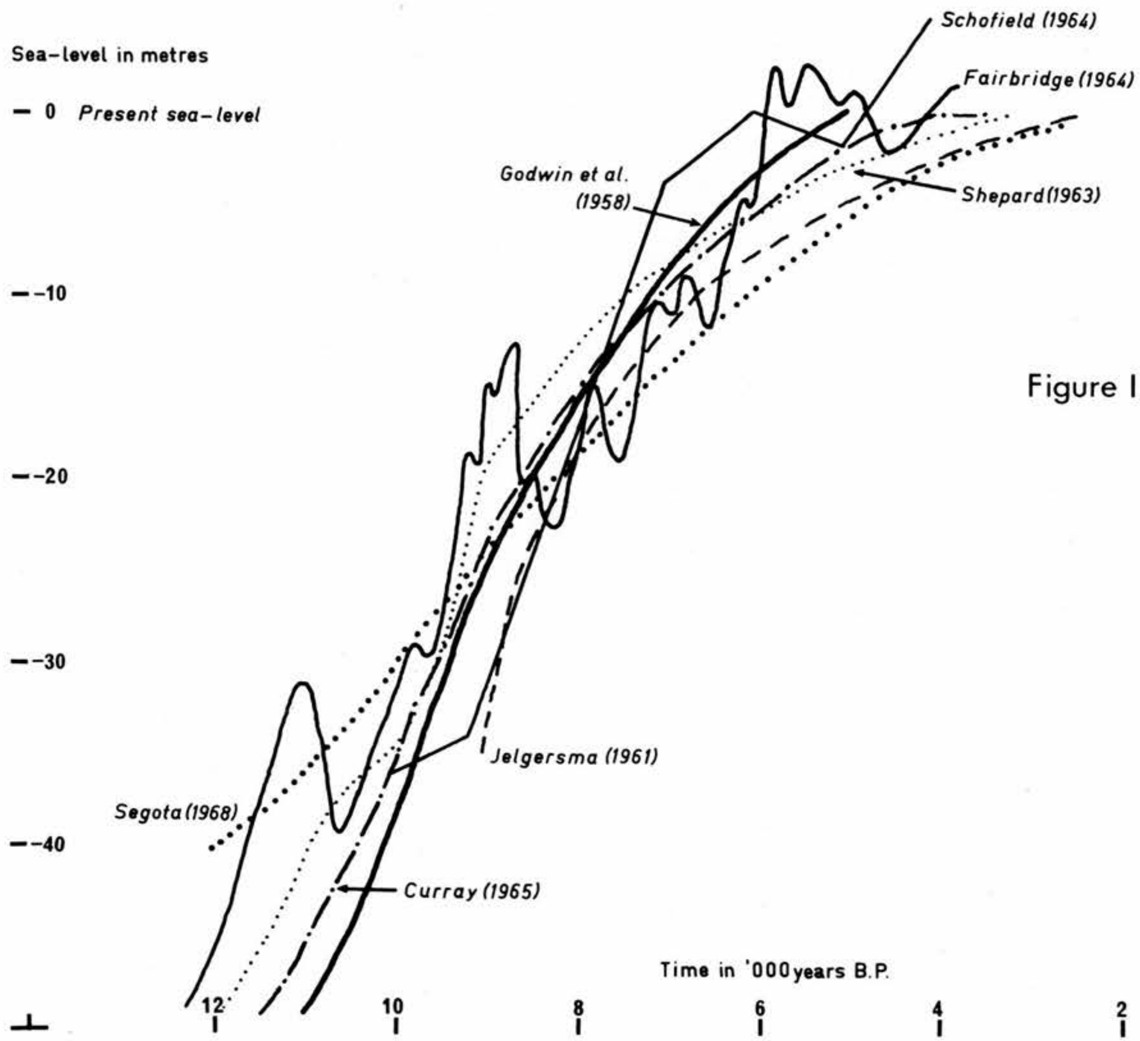


Figure IX.1 Several recent interpretations of eustatic change appears to be most comprehensive and the fact that it is not a smooth curve, but attempts to indicate short term fluctuations, may seem to imply a considerable degree of accuracy. The latter has been questioned by a number of writers, however, (Jelgersma, 1966; Shepard and Curray, 1967; Guilcher, 1969) and certainly in places Fairbridge's curve is relatively far removed from the others (Fig.IX.1). This is particularly true from 6,000 B.P. onwards where Fairbridge shows an oscillating sea-level at times above the present level, while other curves, although differing in the exact date at which the present level was reached, do not rise above it. Of greater consequence in the present study is the discrepancy that exists between 9,200 and 8,600 B.P. where the Fairbridge curve peaks quite sharply and stands between 4.0 and 13.0 m higher than the others. Since the Low Buried Beach was formed during this period, the choice of curve could have a significant effect on the results obtained for variations in level in the Forth valley. It appears that Fairbridge's sea-level for this period is too high, yet there is a considerable range offered by the other curves. Indeed, none of the curves has escaped criticism and the problems have been summarised by Jelgersma (1966) and Guilcher (1969). For the most part the criticisms mention inadequate data or the possibility of tectonic or some other activity affecting the assumptions necessary for the compilation of those data. Most writers accept the inadequacy of present results and point out the need to improve measuring and dating techniques. Any conclusions based on such results must therefore be kept in perspective and this applies to the present study where changes in level cannot be estimated without some indication of world-wide sea-level in the past, however inadequate the latter may be.

Fairbridge's results have already been used in the Forth valley (Sissons, 1967a) in examining changes in level associated with the older Lateglacial raised beaches in East Fife, and the Perth Readvance beaches. For this reason, an attempt was made initially to link the buried beaches with the same curve. From the morphological and stratigraphical evidence it is apparent that the earliest of these features -- the buried gravel layer -- was associated with a period of low, but rising sea-level during which extensive erosion took place. This rise of the sea relative to the land culminated shortly after the readvance of the ice to Menteith and the High Buried Beach was produced. Subsequently, a net fall in sea-level took place with two distinct reversals of the trend bringing the Main and Low Beaches into being. Following the formation of the latter, the downward trend continued and the sea was confined for a short period to the buried estuary of the Forth before rising again in the major Postglacial transgression.

These events took place within a period between about 12,000 and 5,000 B.P. and the relative changes in sea-level have been reproduced in Figure IX.2. Because of the sloping nature of the shorelines, the graph can represent changes at only one point in the area and for present purposes a location immediately east of Abbey Craig was chosen. This gave a complete suite of buried beaches, at the same time allowing a reasonable estimation of the altitude of the buried gravel layer. It was noted in Chapter V that certain patches of gravel lying in the vicinity of the Forth, east of Stirling, could be considered to represent the buried gravel in that area. The

Figure IX.2 Relative sea-level changes at Abbey Craig

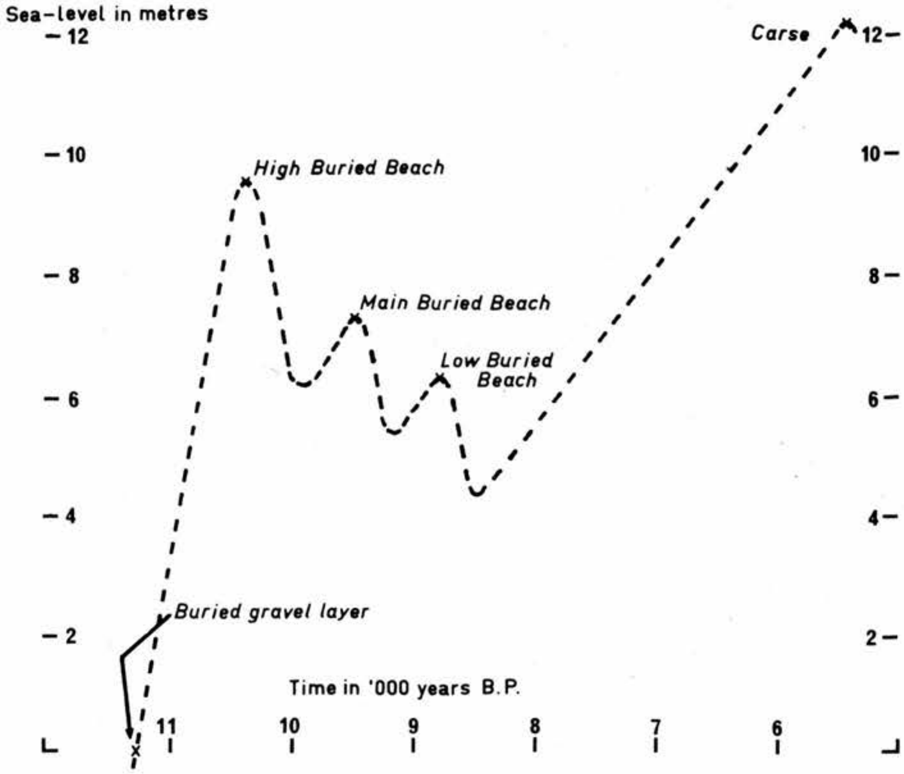
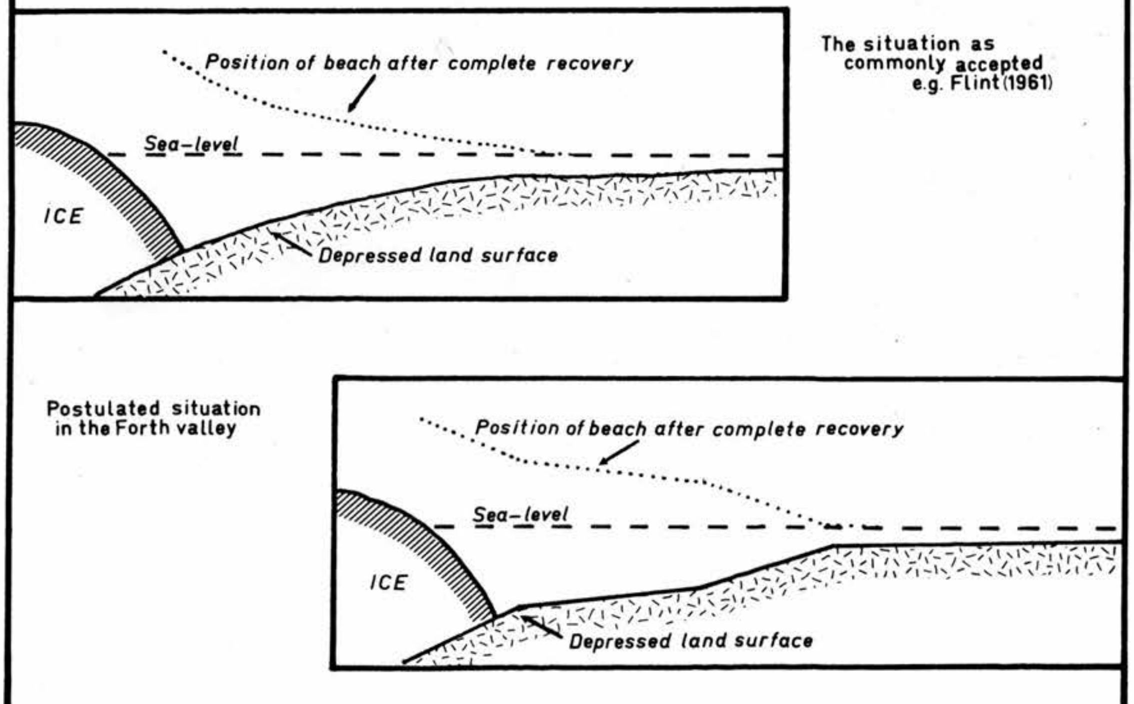


Figure IX.3 The effect of different forms of crustal warping on raised beach development



altitude of the surface of each of these sections lay close to Ordnance Datum and that altitude was used in calculations involving the gravel layer. Unfortunately, no shoreline measurements are available for the buried gravel in this area and there is no shoreline gradient from which they may be estimated. At the same time, the gravel surface shows a considerable altitudinal range in other parts of the Forth, while the date of its formation is less precise than that calculated for any of the other features. Thus, the results obtained using the buried gravel layer must be recognised as likely to be less accurate than those produced from the buried beaches.

The total curve can be divided into three sections, two of which indicate a steady rise in sea-level separated by a third where there is a net downward trend. While the two rising sections have a similar form they have different causes. From approximately 8,500 to 5,500 B.P. the sea-level rose steadily as a result of the final stages of the world-wide decay of ice that followed the last glaciation. In the second case, the rise of the sea relative to the land that began sometime before 11,500 B.P. and culminated about 10,300 B.P. can also be related to glaciation, but in a different way. In part, this earlier rise coincided with the Loch Lomond Readvance producing the apparent anomaly of a rising sea-level while water was being retained on land in the form of ice. Such a situation is explicable in terms of glacio-isostasy, the depression of the land beneath the expanding ice producing an apparent rise in sea-level. While the Stirling area was not covered by ice during this Zone III Readvance, it was sufficiently close to the ice mass to experience the effects of down-warping. This explanation can be applied to the period from about

10,800 B.P. onwards when the ice began to accumulate, but it is possible that the earlier part of the rise may have been eustatically produced as water freed from glaciers and ice-sheets after the earlier Perth Readvance (and its equivalents elsewhere in the world) finally overhauled the isostatically rising land. Thus, the overall rise in sea-level between 11,500 and 10,300 B.P. may well have been due to more than one cause and, in fact, may have been less regular than indicated by the present curve.

The third section of the curve is characterised by a net downward trend from a high of 9.5 m O.D. at 10,300 B.P. to a low of 6.3 m O.D. at 8,800 B.P. It seems likely that the level was lower than 6.3 m both before and after 8,800 B.P., but by how much cannot be calculated at present and the figure of 3.2 m for the overall fall can only be a minimum. These values give an average lowering of the sea relative to the land of 0.21 cm per year. At the same time, an examination of Fairbridge's curve of eustatic changes for the same period, (Fig.IX.1), shows that world-wide sea-level was rising at an average rate of 1.6 cm per year. Since the rise is not duplicated at Abbey Craig, non-eustatic factors must have been sufficiently strong to obscure the trend. As already indicated, the most important non-eustatic factor in the area concerned is glacio-isostasy and its relative importance is apparent from a simple comparison of the two curves.

From the same curves it is possible to calculate the amount of uplift that has taken place. When the High Beach was formed, for example, the sea stood at approximately 39.0 m below its present level, yet the beach is now at an altitude of 9.5 m O.D. close to Abbey Craig, indicating a displacement of 48.5 m in the 10,300 years since it was formed, at an average rate of 0.47 cm per year. This may be illustrated further by reference to the Low Beach which stands at 6.3 m O.D. near Abbey Craig. When it was formed some 8,800 years ago, the sea-level was 15.0 m below the present level, according to Fairbridge. Thus, since its formation there has been 21.3 m of uplift, at an average rate of 0.24 cm per year, or almost half the overall rate since the High Beach was formed. A changing rate of uplift such as this has been recognised frequently and it is commonly considered that the most rapid uplift took place immediately following the decay of the ice and has been slowing down gradually since then (Chapter VIII). However, the isostatic compensation calculated from the buried beaches does not appear to fit that pattern.

In the period between the formation of the High and Main Buried Beaches world-wide sea-level rose by 10.0 m and since the High Beach was not covered that figure must represent a minimal amount of uplift for that period. Furthermore, the height differential between the two beaches is 2.2 m which must have been achieved prior to the building up of the Main Beach, both having undergone the same rate of uplift since then. As a result, the amount of isostatic compensation in the 800 years between the formation of the two beaches must have been at least 12.2 m, or 1.53 cm per year. From Fairbridge's curve the rate of eustatic rise for the same period can be calculated at 1.25 cm per year. In the same way, isostatic uplift between the formation of the Main and Low Beaches took place at a minimum rate of 2.14 cm per year compared with a eustatic rise of 2.0 cm per year.

According to this evidence, uplift in the period between

10,300 and 9,500 B.P. was less rapid than in the years between 9,500 and 8,800 B.P. This is directly contrary to recent results from other parts of the world such as Scandanavia (Lundqvist, 1965) and Arctic Canada (Andrews, 1968) as well as the Forth valley itself (Sissons and Smith, 1965a) all of which show a rapid rise of the land on the initial decay of ice followed by a gradual reduction in the rate with time. In the case of the buried beaches, since the High Beach was formed first and at a time when ice was still at the moraine, the rate of uplift following its formation would be expected to be greater than that following the Main Beach. An explanation of this situation might be pursued in the morphology or glaciology of the area, but since the results are so much at variance with the generally accepted facts, the data themselves might be questioned. To check this, rates of uplift were estimated at Burnbank and at Menteith-Thornhill for the same periods, the results being indicated in Table IX.I.

TABLE IX.I

Average rates of isostatic uplift (in cm/yr) calculated using Fairbridge's (1961) curve of eustatic change

	10,300-9,500	9,500-8,800
Abbey Craig	1.53	2.14
Burnbank	1.45	2.14
Menteith-Thornhill	1.50	2.28

It can be seen that the results support each other and show that throughout the area covered by the buried raised beaches, the rates of uplift were comparable despite a distance of approximately 22.0 km separating the Abbey Craig and Menteith-Thornhill locations. This suggests that the initial results from Abbey Craig were not due to discrepancies peculiar to that area.

Since all the results were based on values of a rising sea-level obtained from Fairbridge's (1961) curve, this was also checked. It was noted above that in the period between 9,200 and 8,600 B.P. that curve gave results considerably greater than those of the other workers (Fig.IX.1) and this could have influenced the uplift figures since the Low Beach, upon which they were partly based, was formed during this period. To test this, further rates of uplift were estimated using other curves of eustatic change.

After Fairbridge, perhaps the most comprehensive curve is that of Shepard (1963) and this has been used in the calculation of isostatic rebound in Arctic Canada (Andrews, 1968, 1969; Andrews, Buckley and England, 1970). Using the results from the buried beaches it was estimated that between 10,300 and 9,500 B.P. the rate of uplift at Abbey Craig was 1.03 cm per year while between the latter date and 8,800 B.P. the rate was reduced to 0.86 cm per year which fits in with the generally accepted pattern of uplift. These results together with rates of uplift calculated from other curves have been presented in Table IX.II below.

TABLE IX.II

Rates of uplift (in cm/yr) at Abbey Craig, calculated using different curves of eustatic change

		10,300-9,500	9,500-8,800
Fairbridge	(1961)	1.53	2.14
Shepard	(1963)	1.03	0.86
Godwin	(1958)	1.52	1.43
Curray	(1965)	1.40	1.29
Segota	(1968)	1.03	0.71

It is evident from these results that a considerable range of values exists for each time period, but it is also apparent that all except those based on Fairbridge's curve indicate less rapid uplift between 9,500 and 8,800 B.P. than in the earlier period. With this in mind, it is suggested that for the particular time period under consideration, Fairbridge's results do not give a sufficiently accurate indication of the position of world sea-level to allow a reasonable estimation of isostatic rebound. Among the values obtained from other curves, however, there is considerable variation and which is most accurate is not immediately clear. On present evidence, the hypothesis of a steadily rising sea-level reaching its present position only relatively recently and supported by the curves of Shepard (1963) and Segota (1968) appears reasonably acceptable (Jelgersma, 1966). It is suggested therefore that the results obtained using either of these two curves may be taken as indicative of the rates of isostatic recovery at Abbey Craig.

To complete an examination of the rates of isostatic and eustatic change associated with the sub-carse features, the buried gravel layer must be examined. From the graph of sea-level changes at Abbey Craig (Fig.IX.2) it is apparent that a substantial rise in sea-level relative to the land took place between the formation of the buried gravel layer and the High Buried Beach. Between these features at present there is a height difference of 9.5 m and it may be noted that this must have been achieved by the time the High Beach had been formed since both were subsequently affected by the same amount of isostatic rebound. Thus at Abbey Craig, between 11,300 and 10,300 sea-level made a vertical gain of 9.5 m over the land. On comparing this with Shepard's (1963) curve (Fig.IX.1) it can be seen that during the same time period, world sea-level rose by only 8.0 m. This being so, the additional 1.5 m gain at Abbey Craig could have been produced by depression of the land accompanying the build up of the Loch Lomond and Menteith ice. This figure may appear low and other curves allow estimates of between zero and 9.0 m depression, but it is suggested that all results are relatively inaccurate due to the general problems in the drawing of the eustatic curves along with the difficulties of obtaining comparable heights and dates for the buried gravel layer. However inaccurate it may be, the result is not unexpected and fits in with the concept of crustal depression accompanying even relatively minor glacial readvances.

After the formation of the Low Buried Beach, sea-level fell for a short period before beginning the rise that produced the Main Postglacial transgression. The similarity between this and the rise that brought the formation of the High Beach has already been noted (Fig.IX.2). Differences exist, however, for the earlier rise appears to have been produced, in part at least, by a depression of the land. During the Postglacial rise it can be shown that both land and sea were rising, the latter more rapidly than the former. The difference in altitude between the Low Beach and the main carse surface at Abbey Craig is 5.9 m and this must have been present by 5,500 B.P. when the carse was formed. At the latter date world sea-level stood at -4.5 m O.D. according to Shepard (1963) therefore the surface of the Low Beach would have been at an altitude of -10.4 m O.D. Since world sea-level stood at -20.0 m O.D. when the Low Beach was formed, isostatic recovery must have been 9.6 m in the 3,300 years between 8,800 and

5,500 B.P., a rate of 0.29 cm per year.

In summary, it can be noted that following the depression produced by the ice of the Loch Lomond Readvance, the land at Abbey Craig began a recovery that continued for at least 5,000 years at a gradually decreasing rate.

The results considered above refer only to conditions in the vicinity of Abbey Craig and to supplement them, rates of uplift were estimated farther west at Burnbank and Menteith-Thornhill (Table IX.III).

TABLE IX.III

Average rates of isostatic uplift (in cm/yr) in the Forth valley

	10,300-9,500	9,500-8,800
Menteith-Thornhill	1.51	1.17
Burnbank	1.48	0.88
Abbey Craig	1.03	0.86

These were based only on evidence from the three buried beaches and the buried gravel layer was not considered, but it can be seen that slight differences exist from area to area. The most westerly location -- Menteith-Thornhill -- has experienced more rapid uplift than the more easterly areas during both time periods. While the variations are small the pattern does correspond to conditions indicated by values of contemporary uplift in north-west Europe which show that the rate of isostatic recovery increases towards the location of the centre of the former ice-mass (West, 1968). All three sites in the Forth lie outwith the limit of the Loch Lomond

Readvance, but, being closest to the former ice margin, the Menteith-Thornhill area would have experienced more rapid uplift than Burnbank or Abbey Craig and this is confirmed by Table IX.III.

This more rapid and presumably lengthier recovery in areas of greater displacement is commonly used to explain the tilting of raised beaches with the greater altitudes found close to the former ice margin. This appears to be the case in the Forth valley, for altitudes on the buried beach shorelines near the former location of the ice at Menteith are greater than those east of Stirling, but the changing gradients of the beach shorelines noted in Chapter VIII raise problems. It is common practice to cite a single gradient for the whole length of a shoreline, (although recently Andrews, Buckley and England (1970) have indicated the presence of curved rather than rectilinear shorelines in Arctic Canada) but it was shown that this could not be applied to the buried beaches, each of which included local variations in gradient. It was suggested that this phenomenon was produced by differences in uplift from place to place in the Forth valley and this may well apply, although it cannot be confirmed from the results quoted above. It is also possible, however, that the initial displacement of the surface by glaciation was not in the form of the smooth curve commonly used to illustrate the situation (Flint, 1961), but rather a line consisting of a number of facets showing sharp rather than gradual change in the amount of displacement away from the ice margin (Fig.IX.3). The gradual recovery of these sections at different rates and for different lengths of time, could then be used to explain the variation in gradient along any one or all of the beaches.

Some support for such a development is provided from Fenno-scandia, where Sauramo (1958) noted sharp changes in the slope of some shorelines. These were attributed to differential movement along hinge-lines in the earth's crust and suggested that recovery after glaciation was not simply a process of regular updoming. Fairbridge (1961) pointed out that such hinge-lines are common in the early stages of isostatic rebound with no less than four being present in certain Finnish beaches formed between 10,000 and 9,000 B.P. As yet, the concept has not been shown to apply to the Scottish raised beaches, but it is suggested that a closer investigation of the geology or glacial and depositional history of certain parts of the Forth valley might provide some clarification of the local situation while a search for buried beaches (or their equivalent) in adjacent areas could lead to the development of shoreline diagrams and isobases that could be examined for further evidence of the presence or absence of hinge-lines.

Stratigraphical comparison.

The relationship between the carse-clay and the buried raised beaches in the Forth has already been described and the possibility of similar relationships existing in other areas where carse-clay is present has been suggested. This will now be examined further.

North of the Firth of Forth, carselands are found in the Carse of Gowrie stretching along the north side of the Tay estuary from a point near Dundee as far as Perth. On the south side of the river near Abernethy a tongue of carse extends up the valley of the River Earn, a tributary of the Tay. The typical stratigraphy of these carselands has long been recognised (Buist, 1841; Chambers, 1848;

Jamieson, 1865; J. Geikie, 1906) and includes elements, such as the carse-clay itself and buried or submerged peat, that are commonly found in the Forth also. The similarity is confirmed from two sites in the Earn where buried peat has been dated at 8421±157 and 8354±143 years B.P., both directly comparable with a result of 8421±157 B.P. for peat in a similar location at Airth, near Stirling (Godwin and Willis, 1961). Most of the early investigators in the Tay, however, were content to note the stratigraphy as far down as the buried peat, often describing it in some detail, but considered the deposits beneath the peat in only a very general way. J. Geikie, for example, in 1906 mentioned an ancient land surface, well preserved in the valleys of the Tay and the Earn, represented by a thick layer of woody peat from which rootlets passed down into the underlying "fluviatile alluvia" which he appears to have considered as part of the 100 foot raised beach clays. It can be noted that the presence of rootlets passing from the buried peat into the deposits of the Low Buried Beach has already been described for the Forth (Chapter III) while the term "100 foot raised beach clays" as used at that earlier time must have encompassed a great variety of deposits and it is suggested that Geikie's "fluviatile alluvia" represented, in part at least, buried beach sediments.

Other workers have mentioned the presence of a landscape on which the buried peat originally grew (Buist, 1841) or implied the presence of a relatively level surface upon which the peat rested (Jamieson, 1865), but the composition of the feature beneath the peat has not been considered in anything but very general terms. Jamieson used the term "glacial-marine beds" for the deposits while Chambers

(1848) introduced slightly more detail in describing a section near Polgavie in the Carse of Gowrie. The section as a whole consisted of 20 feet (6.1 m) of carse-clay resting upon 4 feet (1.2 m) of peat, the latter containing remains of alder and birch with some still in the positions they had occupied while growing in the blue clay beneath the peat. The clay may represent Lateglacial marine deposits, but in the Forth at least they are seldom found with peat resting upon their surface. Again, although the buried beaches of the Forth are never blue in colour, rather they are grey, some allowance can perhaps be made for individual interpretation where colour is concerned. Comparing the stratigraphy of the two areas it is suggested that the Polgavie peat is resting upon buried beach sediments.

More recently, Sissons, Cullingford and Smith (1965) noted the stratigraphy in a valley cut in Lateglacial marine deposits near Glencarse in the Tay estuary and described the following succession: -

3. Carse clay
2. Peat
1. Fine sand

The fine sand was found to be contiguous with the local Lateglacial beach sediments and since no deposits intervened between the peat and the fine sand it was concluded that the valley was not transgressed by the sea until the carse was laid down. From the point of view of the present study, however, a borehole put down close to the mouth of the valley is of particular interest for it indicated the presence of 1.8 foot (0.55 m) of "soft silty clay" immediately beneath the peat, its surface at a height of 4.8 m O.D. It is considered that this might be the innermost edge of a buried beach.

A similar stratigraphical sequence to that in the Tay has been described for the South Esk at Montrose in Angus (Howden, 1870) and the mouth of the River Ythan in Aberdeenshire (Jamieson, 1865), but apart from the Forth and Tay areas, the distribution of the carselands in the east is quite limited. In the west, however, there are two additional areas that merit examination -- namely, the Solway Firth and the Firth of Clyde.

In the Solway, the carselands have stratigraphical elements directly comparable to those already described in the Forth and Tay. Remnants of formerly extensive surface peat are present, for example, in Lochar Moss and the Moss of Cree, both of which rest upon the silts and clays forming the carse in this area (Jardine, 1964). The comparison can be taken further in a number of areas, for buried peat has been located and dated by radio-carbon assay in a number of sites along the Scottish coast of the Solway. Since the work has been undertaken in most cases with the intention of obtaining a date for the onset of the Postglacial transgression, the results are not always directly related to the underlying deposits with which the present study is concerned. However, the collection of the peat for dating usually exposed the adjacent stratigraphy and this can be examined and utilized for comparative purposes.

Beyond the surface peat, carse-clay and buried peat, comparison becomes more difficult because of the variety of deposits present. Of the more recent sites examined (Godwin and Willis, 1960, 1961, 1962; Jardine, 1964; Godwin, Willis and Switsur, 1965) only one, at Redkirk point near the head of the Firth, has a succession that includes deposits directly analogous to those that form the buried beaches in the Forth. Using the site description, the stratigraphy can be outlined as follows: -

7. Carse clay
6. Peat
5. Sandy grey clay
4. Thin bands of peat
3. Ferruginous sand
2. Glacial Till
1. Rock

The upper peat has been dated at 8135±150 B.P. (Godwin and Willis, 1962) and the lower at 10,300±185 B.P. (Godwin, Willis and Switsur, 1965). From the succession itself, the upper peat, sandwiched between 3.7 m of carse-clay and 2.7 m of sandy grey clay, might well have been considered to represent a lens of vegetable matter included in the carse as the latter was forming, the date indicating its very early incorporation. Comparison with the other elements, however, along with the date of the lower peat does not allow this interpretation and it is suggested that the sandy grey clay is the equivalent of certain of the buried beach sediments of the Forth. With its surface at about 3.0 m O.D. it is lower than any of the Forth features, but greater distance from the centre of maximum isostatic uplift would largely explain this. From the bracketing dates provided by the peat layers the sandy clay must have been deposited at the same time as the Main and Low Beaches, but the dating is not exactly coincident. This in itself presents no real problem at this stage, for local conditions in the Forth and Solway, while broadly similar must have differed in detail and with only one exposure of any consequence from the Solway, the comparison can only be general.

Moving north into the Clyde the sediments of the Postglacial beaches also hide buried peat layers. Recent examples in the lower Clyde in Ayrshire have been examined by Jardine (1964). Only one of the successions described bears any obvious relationship to the situation in the Forth. At Enoch Farm, near Girvan, a thin band of buried peat resting upon 1.1 m of laminated clay was dated at 9362±150 B.P. Considering the type of deposit and its age, along with the fact that it lies at approximately 5.0 m O.D., the laminated clay may well be related to the buried beaches. A date of 9020±150 B.P. from buried peat in a second site at Girvan is close to the original as are the figures of 9620±150 and 9530±150 B.P. from Irvine, along the coast to the north. In each of these cases, however, the stratigraphy bears no obvious similarity to that associated with the buried beaches. While this may not disprove any relationship between the sites -- the same sea can have different effects at different points on the coast -- it limits any conclusions to little more than generalizations. Indeed, this is a major problem, for the amount of detailed stratigraphical work in the areas of the Postglacial transgression outside the Forth is very small. Even where the detail is good it is not always directly relevant in the present context. For example, the abundant information on the sub-arctic fossiliferous beds of the west of Scotland has been summarized by Sissons (1967a). These beds are immediately overlain by the sediments of the Postglacial sea and although the two deposits are not always separated by peat, they do not merge, implying a period of lower sea-level before the Postglacial rise, as was the case in the Forth. It may be suggested that the sub-arctic beds are, in part at least, equivalent to the Forth buried beaches, but beyond this it is not possible to be more specific.

Additional comparison might be attempted with the stratigraphy of certain sites in Northern Ireland but the evidence from Scotland illustrates one point more than adequately: nowhere outside the Forth have the sub-carse deposits been investigated in sufficient detail to allow anything more than very general conclusions regarding the situation preceding the Postglacial rise in sea-level. Undoubtedly there are similarities from area to area, as the above paragraphs have shown, but until areas such as the Solway and the Clyde have been studied more intensively the strength of the relationships must remain unknown.

Conclusion.

One of the more obvious conclusions that may be drawn from the present chapter is the great variability in the information available for the period during which the buried beaches were formed. Some is reasonably precise, but much may be used only with suitable qualification. This creates obvious problems when comparison is attempted, as above where the relatively abundant information from the Forth cannot be matched from other areas. Despite this, an examination of the available evidence indicates that the Forth valley is unlikely to be unique as far as the buried beaches are concerned and at the same time, the events that produced these features were not simply local in their mechanisms, but were related to much wider developments in the world as a whole.

CHAPTER X

CONCLUSION

The aims of the present research have been two-fold; firstly, to examine the stratigraphy and sub-carse morphology of the study area and secondly, to interpret the results obtained in terms of internal and external relationships in both time and place.

The morphology of the deposits lying beneath the carselands on the north side of the River Forth was deduced from an examination of the stratigraphy revealed by both shallow hand-boring and deeper commercial boring. Such methods inevitably produced, between boreholes, areas of "dead ground" through which the interpolation of stratigraphy and buried morphology was necessary and, because of the presence of the carse-clay, the overall form of the landscape, that is normally available to the surface geomorphologist for observation and measurement, was not even visible in the present study. However, such problems were minimized by working from a base of accurate quantitative information (as obtained by the combined use of the stratigraphical records collected with a Hiller borer and heights derived by levelling from Ordnance Survey bench-marks) and by the careful location of boreholes. Thus, despite the absence of directly observable features, it is submitted that the landscape revealed by the interpretation of the borehole evidence is essentially similar to that which would be exposed by the complete removal of the carse-clay.

The buried landscape includes areas of fine marine sediments forming raised beaches and coarser sands and gravels of varied origin. In the west, between Menteith and Blairdrummond, buried raised beaches predominate, forming a landscape similar to that of the carse in that it is subdued and composed of relatively fine marine sediments. However, the buried landscape has local variations in colour of sediments, composition and altitude that allow its division into three beaches, designated the High, Main and Low Buried Beaches. Associated with the beaches are the buried valleys of the Forth and Goodie Water along with the sand and gravel of the Menteith outwash and the alluvial fans of the burns that flow off the higher land backing the carse in this area.

In the west the buried beaches dominate the buried landscape, but from Blairdrummond as far as Stirling, outwash and fluvial deposits lie immediately beneath the carse to the exclusion of beach sediments. Originating mainly as outwash issuing from the Teith valley, the sand and gravel was later augmented and rearranged by fluvial activity and now forms the largest continuous morphological unit on the north side of the Forth.

Eastwards from Stirling, elements of the two western areas are present in the buried beaches between Abbey Craig and Menstrie, the alluvial fans of the Ochil Hills and the sand and gravel of the River Devon, but an addition to the buried landscape in this area is the buried gravel layer. Lying mainly in the vicinity of Kincardine-on-Forth, the latter is a marine feature formed prior to the buried beaches and consists of areas of planated rock and till as well as the gravel from which it takes its name.

Thus, over the study area as a whole the buried landscape possesses considerable variety, but a variety that is effectively masked by the carse-clay that makes up the present landscape.

The various elements summarized above indicate the presence north of the Forth of certain sub-carse features bearing a strong similarity to those already encountered south of the river. The buried beaches, for example, were first recognized by Sissons (1966) in the western part of the Carse of Stirling close to the Menteith Moraine and extending eastwards beneath the southern margins of the carse. The presence of similar features along the northern edge of the estuary in which the beaches were formed was not unexpected and this has now been confirmed. In addition, the distribution of the beaches located during the present study combined with that of beaches previously described, indicates the considerable extent of such features in the Forth valley as a whole. For example, the major system shown to be present in the angle of Abbey Craig and the Ochil Hills, east of Stirling, has indicated the existence of the High Buried Beach considerably farther east than previously located, while the patches of beach sediments, such as those at Hill of Drip and Cambus, together with the smaller remnants elsewhere, suggest the possibility of an even wider distribution of buried beaches at some time in the past.

While the buried beaches are the most prominent elements of the sub-carse morphology that can be compared with earlier work, the present study has also confirmed the existence of the buried gravel layer and its associated features on the northern side of the river and has shown that the buried valley of the Forth is part of a system of buried valleys that includes those beneath major rivers such as the Teith and the Devon and smaller streams such as the Goodie Water.

This supplements earlier evidence from the south side of the Forth, indicating buried valleys probably initiated during the period of low sea-level that preceded the formation of the buried beaches (Sissons, 1969). Other elements of the buried morphology to the north of the river, such as the extensive buried outwash of the Teith and the massive alluvial fans of the Ochils have no real equivalent to the south as far as size is concerned. This may be explained by the lack of major tributaries (except for the River Carron) joining the Forth from the south, the difference in relief to the north and south of the valley and the distribution of ice during the final stages of the last glaciation. The difference is largely one of scale in the case of the alluvial fans. The stratigraphy of those lying along the Ochil front shows that they were forming in Lateglacial times and have continued to grow with varying rapidity since then. Using evidence from the Grangemouth-Falkirk area, Sissons (1969) has inferred a limited amount of fluvial activity during the formation of the buried gravel layer and it is not unlikely that similar action was taking place at various points along the southern margin of the Forth valley where streams passed out from the hills. The alluvial fans that exist along the edge of the Campsie Fells, for example, might be compared to those of the Ochils and it seems probable that they would show similar lengthy development. Such similarities and the existence of more obviously comparable features on both sides of the river helps to establish the basic unity of the landscape that lies beneath the carse-clay of the Forth valley.

Although certain local conditions, such as the size of the estuary or its position with respect to the areas of the Zone III glaciation, might help to explain the considerable development of the buried beaches in the Forth, they are unlikely to be unique to that area, particularly when the influence of eustatic and isostatic changes are taken into consideration. It has been suggested (Chapter IX) that likely locations for similar features in other parts of Scotland would be in estuarine areas such as the Firths of Tay, Clyde and Solway in which deposits similar to those of the Forth carselands are known to exist. The sea-levels associated with the buried beaches probably produced features on the open coast also, although with the relatively short time spans during which the sea stood at a particular level, erosion would have been limited while the lack of material compared with the estuarine locations would have severely restricted the development of depositional forms. Thus, initial investigation in the estuarine areas noted above would appear likely to be more fruitful than work carried out on the open coast.

In the case of the buried gravel layer, however, the reverse may be true. The gravel layer is somewhat anomalous in that it represents a period of extensive marine erosion in an environment normally considered to be more conducive to deposition. It has been suggested (Chapter V) that the buried gravel layer came into being at a time when easterly winds were dominant in the Firth of Forth, producing an increased storminess that resulted in increased erosion. Such developments must have been paralleled on the North Sea coast of Scotland where increased exposure would have produced even greater erosion. Taking the altitude of the gravel layer in the Forth into consideration, it is probable that any equivalent of that layer along the east coast would be submerged off the present coastline. In such a position its investigation and measurement would not be without problems, but provided they could be overcome, the results might help to clarify the events that led to the formation of the buried gravel layer and its associated features.

Any equivalent of the buried gravel layer that might be submerged off the east coast of Scotland would be largely free from the effects of sub-aerial processes at the present time. If, as appears likely, this protection began shortly after the gravel layer came into being, the form of the feature would be relatively unaltered. The same applies to a considerable extent to the gravel layer of the Forth valley and to the buried beaches. Since they lie beneath the carse-clay, they have not been subject to erosion or weathering for the last 5000-6000 years. Prior to their submergence and burial some stream erosion did take place, particularly in the west, but on the whole they are remarkably well preserved. They are much better preserved, in fact, than the exposed raised beaches which have been altered over the years by geomorphological agencies and by the activities of man. As a result, the form of many of these exposed features must have changed significantly since they were produced, while their mechanical and chemical composition must have suffered under the effects of man's settlement and development of agriculture. In contrast the buried landscape of the Forth provides relatively extensive, well preserved segments of raised beaches. Because of the relatively simple and easily recognizable stratigraphical sequence with which they are associated, the problems often involved in the recognition of features as raised beaches appear less likely to apply. While not attempting to minimize the problems inherent in the study of buried beaches or their equivalents, it is suggested that investigation to establish their presence or absence in other parts of Scotland would be most beneficial, not only in terms of local geomorphology, but also in terms of more universal factors such as sea-level change or isostatic rebound.

The present study, for example, has confirmed the existence of a period of considerable sea-level oscillation during approximately 6000 years preceding the maximum of the Postglacial transgression. Accompanying, and partly explaining, these variations was a change in the level of the land produced by isostatic recovery following the decay of glacial ice. Examination and measurement of the buried beaches and their comparison with eustatic changes allowed rates of isostatic rebound to be calculated for the area. These fitted in with the generally accepted pattern of decreasing rapidity of uplift with time and with distance from the centre of maximum depression of the land, but the problems involved in reaching this conclusion amply illustrated the general inadequacy of the data employed in the estimation of eustatic change.

In addition, measurements along the buried beaches indicated shoreline tilting, considered to be produced by differential uplift. However, the results in this case were found to be at variance with the normal pattern of a beach shoreline with a single gradient throughout its length, for each shoreline was found to consist of a number of segments, each with a different gradient. It is possible that these conditions may be peculiar to the Forth valley or even to the buried beaches, or, as was indicated in Chapter IX, they may be explicable in terms of theories postulated by certain Scandanavian workers, but until the present information can be augmented, perhaps from similar features that may exist elsewhere in Scotland, the situation cannot be clarified.

At the present time, there is probably more information available on the raised beaches -- both buried and exposed -- of the Forth valley, than on those of any other area of comparable size in Scotland. The visible raised beaches have been studied there and elsewhere in Scotland for more than a century yet it is apparent that many problems still await solution. Perhaps the work on the buried beaches, which is only beginning, will initially add to these difficulties, but it is to be hoped that it will at least partially solve the earlier problem of limited information and reduce the misconceptions that arose as a result. The magnitude of the present information gap with respect to the buried beaches is apparent when it is considered that they, together with their associated features, represent a period of 5000-6000 years of geomorphological activity and 5000-6000 years of changes in the relative positions of land and sea as yet virtually untouched by geomorphologists. It is suggested that intensive studies such as those described for the Forth valley must be carried out in other parts of Scotland, probably initially in those areas that bear some stratigraphical and morphological similarity to the carselands of the Forth, if this gap is to be adequately filled.

APPENDIX A

BOREHOLE LOGS

BH 1	13.3 m O.D.	NS 6602 9942
0 - 191 cms	Carse.	
191 + cms	Tough, grey/brown, silty sand with some shell fragments in top 2-3 cms.	
BH 2	13.6 m O.D.	NS 6602 9937
0 - 244 cms	Carse.	
244 + cms	Tough, grey/brown, silty sand. Quite large shell fragments in top 2-3 cms.	
BH 3	13.6 m O.D.	NS 6602 9932
0 - 249 cms	Carse.	
249 + cms	Tough, clayey sand.	
BH 4	13.5 m O.D.	NS 6602 9927
0 - 252 cms	Carse.	
252 + cms	Slightly purple/pink, clayey sand.	
BH 5	13.9 m O.D.	NS 6602 9947
0 - 100 cms	Orange/red sand.	
100 - 260 cms	Carse.	
260 - 266 cms	Transition zone with shells.	
266 + cms	Grey/brown, clayey sand with mica(?) and shell fragments.	
BH 6	14.2 m O.D.	NS 6602 9952
0 - 100 cms	Reddish sand.	
100 - 296 cms	Carse.	
296 + cms	Grey/brown, clayey sand.	
BH 7	14.4 m O.D.	NS 6602 9957
0 - 258 cms	Carse.	
258 + cms	Pinky/grey, clayey sand with slight lamination.	
BH 8	14.6 m O.D.	NS 6602 9961
0 - 160 cms	Carse/sand mixture.	
160 - 180 cms	Waterlogged, brown sand.	
180 - 271 cms	Carse-clay.	
271 + cms	Pinkish/brownish/grey, clayey sand.	
BH 9	13.5 m O.D.	NS 6602 9922
0 - 247 cms	Carse.	
247 + cms	Grey/brown, clayey sand. Very tough.	

BH 10		13.5 m O.D.	NS 6602 9917
0 - 253 cms	Carse.		
253 + cms	Brownish/pink, clayey sand.		
BH 11		13.6 m O.D.	NS 6602 9912
0 - 268 cms	Carse.		
268 + cms	Pinkish, clayey sand.		
BH 12		13.6 m O.D.	NS 6602 9907
0 - 277 cms	Carse.		
277 + cms	Pinkish/purplish/brown, sandy clay.		
BH 13		13.6 m O.D.	NS 6602 9902
0 - 376 cms	Carse.		
376 + cms	Grey, slightly brown, sandy clay. Very tough.		
BH 14		13.6 m O.D.	NS 6602 9903
0 - 311 cms	Carse.		
311 + cms	Brownish/grey, sandy clay.		
BH 15		13.7 m O.D.	NS 6602 9904
0 - 334 cms	Carse.		
334 + cms	Pinkish/grey, sandy clay.		
BH 16		13.6 m O.D.	NS 6602 9901
0 - 407 cms	Carse.		
407 + cms	Pinkish/grey, sandy clay.		
BH 17		13.4 m O.D.	NS 6602 9896
0 - 440 cms	Carse.		
440 + cms	Grey, sandy silt.		
BH 18		13.5 m O.D.	NS 6602 9895
0 - 609 cms	Carse.		
609 + cms	Rock(?).		
BH 19		13.5 m O.D.	NS 6602 9894
0 - 613 cms	Carse.		
613 + cms	Rock(?).		
BH 20		13.5 m O.D.	NS 6603 9894
0 - 612 cms	Carse.		
612 + cms	Rock(?).		
BH 21		13.6 m O.D.	NS 6602 9888
0 - 639 cms	Carse.		
639 - 655 cms	Black, coarse, wet sand.		
655 + cms	Tough, plastic, grey, sandy clay with pink streaks.		
BH 22		13.6 m O.D.	NS 6602 9890
0 - 610 cms	Carse.		
610 - 632 cms	Mixture of carse-clay and coarse, black sand.		
632 + cms	Grey/brown, sandy clay with pinkish patches.		

BH 23		13.5 m O.D.	NS 6602 9892
0 - 628 cms	Carse.		
628 + cms	Rock(?).		
BH 24		12.8 m O.D.	NS 6602 9882
0 - 590 cms	Carse.		
590 - 601 cms	Transition zone - carse becomes more sandy eventually giving way to black sand.		
601 + cms	Very coarse sand or gravel.		
BH 25		11.7 m O.D.	NS 6602 9878
0 - 165 cms	Red/brown sand.		
165 - 182 cms	Dark brown sand.		
182 - 423 cms	Carse, - too tough for further penetration.		
BH 26		12.7 m O.D.	NS 6602 9872
0 - 591 cms	Carse.		
591 + cms	Gravel or rock.		
BH 27		13.3 m O.D.	NS 6602 9868
0 - 583 cms	Carse.		
583 + cms	Tough, grey, silty sand with numerous shell fragments (*Cardium*?).		
BH 28		13.4 m O.D.	NS 6602 9860
0 - 404 cms	Carse.		
404 - 409 cms	Carse/peat transition.		
409 - 437 cms	Peat, including flattened twigs and red coloured seeds with polished surfaces.		
437 + cms	Dark grey, silty sand.		
BH 29		13.0 m O.D.	NS 6602 9855
0 - 460 cms	Carse, - some peat fragments at base.		
460 + cms	Grey, silty sand.		
BH 30		13.4 m O.D.	NS 6602 9850
0 - 414 cms	Carse.		
414 - 441 cms	Peat, including red seeds.		
441 + cms	Grey, silty sand with some peat mixed in top 2-3 cms.		
BH 31		13.3 m O.D.	NS 6602 9845
0 - 434 cms	Carse - becoming more silty at c.400 cms.		
434 - 440 cms	Peat.		
440 + cms	Grey, silty sand with vegetation fragments down to c.5-6 cms in the deposit.		
BH 32		13.2 m O.D.	NS 6602 9841
0 - 417 cms	Carse.		
417 - 443 cms	Peat. Large piece of wood on top, also red seeds.		
443 + cms	Grey, silty sand.		
BH 33		13.4 m O.D.	NS 6602 9837
0 - 600 cms	Carse.		
600 + cms	Black, silty sand.		

BH 34	13.3 m O.D.	NS 6602 9832
0 - 406 cms	Carse.	
406 - 435 cms	Peat.	
435 - 440 cms	Transition zone.	
440 + cms	Grey, silty sand.	

BH 35	14.2 m O.D.	NS 6603 9828
0 - 43 cms	Moss Peat.	
43 - 640 cms	Carse.	
640 + cms	Grey, silty sand.	

BH 36	14.9 m O.D.	NS 6603 9822
0 - 129 cms	Moss Peat.	
129 - 629 cms	Carse - with some vegetable matter at c.145 cms.	
629 - 640 cms	Peat.	
640 + cms	Grey, silty sand.	

BH 37	14.7 m O.D.	NS 6603 9819
0 - 94 cms	Moss Peat.	
94 - 98 cms	Transition zone.	
98 - 552 cms	Carse.	
552 - 556 cms	Peat.	
556 - 570 cms	Transition zone.	
570 + cms	Grey, silty sand.	

BH 38	14.7 m O.D.	NS 6603 9815
0 - 126 cms	Moss peat, woody near base.	
126 - 135 cms	Transition zone.	
135 - 572 cms	Carse.	
572 - 606 cms	Peat.	
606 + cms	Grey, silty sand.	

BH 39	14.7 m O.D.	NS 6604 9811
0 - 112 cms	Moss Peat.	
112 - 116 cms	Transition zone.	
116 - 570 cms	Carse.	
570 - 590 cms	Peat.	
590 + cms	Grey, silty sand.	

BH 40	14.1 m O.D.	NS 6604 9808
0 - 46 cms	Moss Peat.	
46 - 48 cms	Transition zone.	
48 - 508 cms	Carse.	
508 - 529 cms	Peat, very woody at 522 cms.	
529 + cms	Grey, silty sand.	

BH 41	13.8 m O.D.	NS 6604 9803
0 - 15 cms	Moss Peat.	
15 - 470 cms	Carse. Shells at base.	
470 - 481 cms	Peat.	
481 + cms	Grey, silty sand.	

BH 42	13.8 m O.D.	NS 6604 9803
0 - 12 cms	Moss Peat.	
12 - 543 cms	Carse. Lowest 20-25 cms very rich in shell fragments - some up to 1.5 cms across.	
543 + cms	Slightly brown/grey, silty sand.	
BH 43	13.3 m O.D.	NS 6605 9794
0 - 410 cms	Carse.	
410 - 421 cms	Peat.	
421 - 427 cms	Transition zone.	
427 + cms	Grey, silty sand.	
BH 44	13.2 m O.D.	NS 6605 9789
0 - 420 cms	Carse.	
420 - 426 cms	Shell-bed. Large fragments. Carse quite sandy among shells.	
426 - 609 cms	Carse, still very shelly but dispersed between 521 and 565 cms.	
609 + cms	Grey sand. No sharp change and carse seems to merge with the lower deposit. Shells are in good condition. Mainly *Cardium* - both valves preserved together in several cases. Numerous small gastropods and possibly *Ostrea*.	
BH 45	13.2 m O.D.	NS 6605 9785
0 - 404 cms	Carse. Shells at base.	
404 + cms	Tough, grey, silty sand.	
BH 46	13.2 m O.D.	NS 6606 9780
0 - 472 cms	Carse.	
472 - 479 cms	Woody material.	
479 - 487 cms	Deposit similar to carse in colour but more silty. Seems to be a mixture of wood, carse and silty sand.	
487 + cms	Grey, silty sand.	
BH 47	13.2 m O.D.	NS 6608 9776
0 - 459 cms	Carse - some peat and wood fragments at c.50 cms.	
459 - 463 cms	Peat.	
463 + cms	Grey, silty sand.	
BH 48	13.2 m O.D.	NS 6610 9771
0 - 413 cms	Carse - some peat at c.30 cms.	
413 - 450 cms	Peat.	
450 - 453 cms	Transition zone.	
453 + cms	Grey, green, silty sand.	
BH 49	13.2 m O.D.	NS 6614 9769
0 - 433 cms	Carse.	
433 - 466 cms	Peat.	
466 + cms	Grey, silty sand.	
BH 50	13.1 m O.D.	NS 6616 9765
0 - 440 cms	Carse.	
440 - 471 cms	Peat, woody at top.	
471 + cms	Grey, silty sand.	

BH 51	13.1 m O.D.	NS 6620 9761
0 - 435 cms	Carse. Sandy with shells near base.	
435 - 468 cms	Peat.	
468 - 473 cms	Transition zone.	
473 + cms	Grey, silty sand.	
BH 52	13.2 m O.D.	NS 6622 9759
0 - 443 cms	Carse.	
443 - 470 cms	Peat.	
470 - 473 cms	Transition zone.	
473 + cms	Grey, silty sand.	
BH 53	13.1 m O.D.	NS 6626 9755
0 - 452 cms	Carse. Sandy with shell fragments near base.	
452 - 474 cms	Mixture of grey/brown, sandy material and peat, also including shells.	
474 + cms	Grey sand.	
BH 54	13.0 m O.D.	NS 6629 9750
0 - 415 cms	Carse.	
415 - 442 cms	Peat.	
442 + cms	Grey, silty sand.	
BH 55	13.2 m O.D.	NS 6626 9746
0 - 455 cms	Carse. Very sandy at junction with peat.	
455 - 471 cms	Peat.	
471 + cms	Grey, silty sand.	
BH 56	13.1 m O.D.	NS 6623 9741
0 - 453 cms	Carse. Sand and shells in bottom 5-6 cms.	
453 + cms	Peat. Impossible to penetrate beyond 490 cms.	
BH 57	13.0 m O.D.	NS 6621 9739
0 - 540 cms	Carse.	
540 - 550 cms	Possibly peat, exact thickness not known.	
550 + cms	Grey/green, silty sand.	
BH 58	12.8 m O.D.	NS 6619 9734
0 - 542 cms	Carse.	
542 + cms	Dark grey, silty clay.	
BH 59	11.7 m O.D.	NS 6619 9730
0 - 359 cms	Carse.	
359 - 402 cms	Peat, with tree at base.	
402 + cms	Grey, silty clay.	
BH 60	12.2 m O.D.	NS 6619 9725
0 - 409 cms	Carse.	
409 - 416 cms	Transition zone.	
416 - 440 cms	Peat.	
440 + cms	Grey, silty clay.	

BH 61	12.1 m O.D.	NS 6619 9720
0 - 392 cms	Carse.	
392 - 396 cms	Transition zone.	
396 - 422 cms	Peat.	
422 + cms	Grey, silty clay with numerous vegetable fragments.	
BH 62	12.2 m O.D.	NS 6619 9715
0 - 585+ cms	Carse, becoming increasingly sandy downwards. Samples at 511, 523, 573, and 585 cms all showed this sandy version of the carse. No sharp transition.	
BH 63	12.7 m O.D.	NS 6601 9685
0 - 710+ cms	Carse, base not reached. Sample at 710 cms was dark blue/grey, smelly carse which was difficult to penetrate.	
BH 64	12.2 m O.D.	NS 6600 9640
0 - 470+ cms	Carse, base not reached. Sample at 470 cms was tough, dark blue/grey, smelly clay.	
BH 65	11.6 m O.D.	NS 6660 9619
0 - 500+ cms	Carse, becoming sandier downwards and giving way at c.336 cms to layers of sand and clay. Similar sample examined at 500 cms.	
BH 66	10.5 m O.D.	NS 6660 9600
0 - 150 cms	Red, clayey sand.	
150 + cms	Carse, very tough and slightly brown. Similar sample at 400 cms.	
BH 67	13.7 m O.D.	NS 6792 9839
0 - 73 cms	Carse, top 6-9 cms a mixture of carse-clay and material washed off slope. Becoming sandier downwards.	
73 + cms	Red/maroon sand and gravel.	
BH 68	13.1 m O.D.	NS 6793 9831
0 - 260 cms	Carse. Sandy red near top (O.R.S.?).	
260 + cms	Rock or gravel(?).	
BH 69	13.7 m O.D.	NS 6796 9832
0 - 278 cms	Carse. Sandy red at top, very dark blue towards base.	
278 + cms	Gravel(?).	
BH 70	13.8 m O.D.	NS 6797 9832
0 - 215 cms	Carse. Certain amount of brown, soft, woody deposit immediately below surface. Carse very sandy and brownish/grey in colour.	
215 + cms	Rock or gravel(?).	
BH 71	13.8 m O.D.	NS 6798 9834
0 - 115 cms	Carse.	
115 + cms	Gravel(?).	

BH 72		13.1 m O.D.	NS 6792 9830
0 - 428 cms	Carse. Carse very sandy near base with considerable proportion of shell fragments in grey, sandy matrix.		
428 + cms	Rock or gravel(?).		
BH 73		12.9 m O.D.	NS 6789 9830
0 - 449 cms	Carse.		
449 + cms	Grey sand. Boring stopped by toughness of the sand at 458 cms.		
BH 74		12.8 m O.D.	NS 6785 9829
0 - 472+ cms	Carse. Becomes quite sandy at c.467 cms but no sharp change.		
BH 75		13.0 m O.D.	NS 6777 9826
0 - 485+ cms	Carse. Very tough.		
BH 76		12.9 m O.D.	NS 6804 9829
0 - 274 cms	Carse with bands of sand and shells.		
274 - 357 cms	Red sand and stones.		
357 + cms	Yellow sand with clay.		
BH 77		13.2 m O.D.	NS 6804 9829
0 - 293 cms	Carse, very stoney on top.		
293 + cms	Red/maroon gravel (O.R.S.?).		
BH 78		14.1 m O.D.	NS 6804 9830
0 - 20 cms	Red/brown sandy clay.		
20 + cms	Rock(?).		
BH 79		13.6 m O.D.	NS 6804 9830
0 - 244 cms	Carse.		
244 + cms	Gravel(?).		
BH 80		12.7 m O.D.	NS 6804 9827
0 - 349 cms	Carse. Quite sandy at top.		
349 - 354 cms	Sand and vegetable matter.		
354 + cms	Greyish/yellow, clayey sand.		
BH 81		12.7 m O.D.	NS 6803 9824
0 - 378 cms	Carse.		
378 + cms	Tough, grey sand.		
BH 82		12.6 m O.D.	NS 6800 9820
0 - 440 cms	Carse.		
440 + cms	Tough, grey sand.		
BH 83		12.6 m O.D.	NS 6798 9817
0 - 486 cms	Carse.		
486 + cms	Grey sand.		
BH 84		12.3 m O.D.	NS 6792 9812
0 - 456 cms	Carse.		
456 + cms	Tough, grey sand.		

BH 85		12.3 m O.D.	NS 6792 9806
0 - 487 cms	Carse.		
487 + cms	Tough, grey sand.		
BH 86		12.1 m O.D.	NS 6791 9799
0 - 433 cms	Carse.		
433 + cms	Tough, grey sand.		
BH 87		12.2 m O.D.	NS 6790 9790
0 - 486 cms	Carse. Very shelly near base, fragments suggest *Mytilus* and *Ostrea*.		
486 + cms	Tough, grey sand.		
BH 88		10.7 m O.D.	NS 6793 9785
0 - 316 cms	Carse. Abundant shells in bottom 50 cms.		
316 + cms	Tough, grey, silty sand.		
BH 89		12.0 m O.D.	NS 6794 9780
0 - 462 cms	Carse. Very tough.		
462 + cms	Tough, grey/brown sand, slightly silty.		
BH 90		9.6 m O.D.	NS 6796 9777
0 - 280+ cms	Carse. Too tough to penetrate beyond 280 cms.		
BH 91		11.5 m O.D.	NS 6798 9775
0 - 415+ cms	Tough carse.		
BH 92		12.7 m O.D.	NS 6798 9770
0 - 600+ cms	Carse, exceedingly tough.		
BH 93		12.9 m O.D.	NS 6799 9766
0 - 750 cms	Carse. Becomes increasingly tough downwards.		
750 + cms	Grey, sandy deposit.		
BH 94		12.3 m O.D.	
0 - 722 cms	Carse. Shell fragments at base.		
722 + cms	Tough, grey sand.		
BH 95		12.8 m O.D.	NS 6802 9748
0 - 816 cms	Carse. Very tough downwards.		
816 + cms	Gravel or very coarse sand.		
BH 96		12.8 m O.D.	NS 6803 9733
0 - 815 cms	Carse.		
815 + cms	Gravel(?).		
BH 97		12.6 m O.D.	NS 6804 9719
0 - 698 cms	Carse.		
698 + cms	Tough, grey sand.		
BH 98		9.3 m O.D.	NS 6602 9712
0 - 190+ cms	Carse. Sandy at top.		

BH 99	13.3 m O.D.	NS 6968 9810
0 - 132 cms	Carse. Top 50 cms mainly red sand.	
132 + cms	Red/brown sand with maroon fragments.	
BH 100	13.7 m O.D.	NS 6968 9809
0 - 40 cms	Red sand.	
40 + cms	Rock or rock fragments.	
BH 101	13.1 m O.D.	NS 6968 9808
0 - 60 cms	Red sand.	
60 - 208 cms	Carse. Shells at base.	
208 + cms	Gravel or rock fragments.	
BH 102	13.2 m O.D.	NS 6968 9806
0 - 322 cms	Carse.	
322 - 396 cms	Peat.	
396 + cms	Light grey, silty clay.	
BH 103	13.1 m O.D.	NS 6968 9807
0 - 305 cms	Carse.	
305 - 372 cms	Peat.	
372 + cms	Grey/green, silty clay.	
BH 104	12.5 m O.D.	NS 6969 9801
0 - 331 cms	Carse.	
331 - 403 cms	Peat.	
403 + cms	Grey, silty sand.	
BH 105	13.0 m O.D.	NS 6963 9791
0 - 385 cms	Carse.	
385 - 415 cms	Peat, woody at top.	
415 - 462 cms	Mixture of peat and silty clay.	
462 + cms	Grey, silty sand.	
BH 106	12.9 m O.D.	NS 6964 9795
0 - 359 cms	Carse.	
359 - 392 cms	Peat, woody near top.	
392 - 428 cms	Grey/green, silty clay with vegetable matter.	
428 + cms	Grey, silty sand.	
BH 107	13.1 m O.D.	NS 6965 9783
0 - 420 cms	Carse.	
420 - 455 cms	Thin layer of peat resting on grey/green, silty clay with peat fragments.	
455 + cms	Grey, silty sand.	
BH 108	13.0 m O.D.	NS 6965 9783
0 - 466 cms	Carse.	
466 + cms	Grey, silty sand.	
BH 109	13.1 m O.D.	NS 6968 9774
0 - 500+ cms	Carse. Very tough.	

BH 110	13.0 m O.D.	NS 6968 9769
0 - 514+ cms	Carse. Very tough.	
BH 111	13.0 m O.D.	NS 6968 9765
0 - 400+ cms	Carse. Very tough.	
BH 112	12.9 m O.D.	NS 6967 9747
0 - c540 cms	Carse. Very tough with layers of sand.	
540 + cms	Tough, blue/black sand.	
BH 113	8.3 m O.D.	NS 6967 9727
0 - 259 cms	Carse. Slightly sandy at top.	
259 + cms	Carse-like deposit, but brownish and more sandy.	
BH 114	11.9 m O.D.	NS 6977 9717
0 - 120+ cms	Carse. Further penetration impossible.	
BH 115	11.9 m O.D.	NS 6975 9714
0 - 542+ cms	Carse. Becomes very blue downwards with included layers of sand and shells.	
BH 116	12.6 m O.D.	NS 6974 9705
0 - 405+ cms	Tough carse. Dark blue, smelly clay with occasional layers of sand in places.	
BH 117	11.8 m O.D.	NS 6974 9693
0 - 465+ cms	Tough carse. Sandy with depth.	
BH 118	11.3 m O.D.	NS 6974 9685
0 - 321+ cms	Carse. Blue clay, somewhat sandy with depth.	
BH 119	10.8 m O.D.	NS 6975 9674
0 - 174+ cms	Tough carse. Very red near the top, probably due to mixture of sand from the Forth.	
BH 120	15.2 m O.D.	NN 6531 0015
0 - 164 cms	Clay/sand/peat mixture in top 60 cms but mainly peat, with woody fragments beyond this.	
164 - 170 cms	Transition, grey, peat/clay zone.	
170 + cms	Grey, shelly sand.	
BH 121	15.8 m O.D.	NN 6531 0015
0 - 100 cms	Brown sand with stones.	
100 - 202 cms	Peat, containing considerable clay below c.170 cms.	
202 + cms	Grey sand.	
BH 122	16.5 m O.D.	NN 6531 0015
0 - 100 cms	Brown sand.	
100 - 115 cms	Peaty sand.	
115 + cms	Rock fragments.	
BH 123	15.1 m O.D.	NN 6531 0015
0 - 40 cms	Sand/clay/peat mixture.	
40 - 168 cms	Peat with wood.	
168 + cms	Grey sand with slight pink tinge.	

BH 124	15.1 m O.D.	NN 6530 0012
0 - 40 cms	Sandy clay becoming peaty.	
40 - 172 cms	Peat.	
172 + cms	Rock or big gravel.	
BH 125	14.8 m O.D.	NN 6529 0010
0 - 125 cms	Surface peat.	
125 + cms	Grey sand and gravel. Some pink coloration.	
BH 126	14.7 m O.D.	NN 6528 0008
0 - 131 cms	Peat with peat/clay mixture in top 0.5 m.	
131 + cms	Coarse, grey, sandy gravel.	
BH 127	14.3 m O.D.	NN 6527 0004
0 - 134 cms	Surface peat.	
134 - 139 cms	Peat/clay transition.	
139 + cms	Grey sand with some pink coloration.	
BH 128	13.6 m O.D.	NN 6525 0001
0 - 30 cms	Surface peat with sand/clay mixture.	
30 - 87 cms	Carse-clay with reeds and root fragments in top 20 cms.	
87 - 122 cms	Peat.	
122 + cms	Grey/brown, silty sand.	
BH 129	13.9 m O.D.	NN 6526 0000
0 - 34 cms	Surface peat.	
34 - ? cms	Carse-clay with roots and other vegetable matter.	
? - 137 cms	Peat.	
137 + cms	Gravel(?).	
BH 130	14.1 m O.D.	NN 6526 0003
0 - 26 cms	Surface peat.	
26 - 27 cms	Clay/peat mixture.	
27 - 139 cms	Peat.	
139 - 144 cms	Grey, peaty, clay transition mixture.	
144 + cms	Pinkish sand.	
BH 131	13.8 m O.D.	NS 6519 9994
0 - 183 cms	Carse.	
183 - 229 cms	Peat.	
229 - 233 cms	Clay/peat transition.	
233 + cms	Pinkish sand with grey streaks.	
BH 132	13.8 m O.D.	NS 6514 9988
0 - 177 cms	Carse.	
177 - 202 cms	Peat, woody at base.	
202 + cms	Pinkish/grey sand. Grey at top, becoming pink downwards.	
BH 133	13.7 m O.D.	NS 6511 9982
0 - 196 cms	Carse.	
196 - 202 cms	Peat fragments.	
202 + cms	Sandy version of carse becoming slightly pink or grey/brown downwards.	

BH 134	12.9 m O.D.	NS 6492 9958
0 - 474 cms	Wet, red and brown sand.	
474 + cms	Blue/black sand.	
BH 135	13.4 m O.D.	NS 6493 9962
0 - 450+ cms	Carse. Blue/black sand in places.	
BH 136	13.7 m O.D.	NS 6496 9965
0 - 193 cms	Carse.	
193 + cms	Pink/brown, silty sand.	
BH 137	13.6 m O.D.	NS 6495 9964
0 - 237 cms	Carse.	
237 + cms	Grey, silty sand with pink and brown streaks.	
BH 138	13.6 m O.D.	NS 6495 9963
0 - 304 cms	Carse. Very blue towards base.	
304 + cms	Grey/pink, silty sand.	
BH 139	13.4 m O.D.	NS 6494 9963
0 - 358 cms	Carse, toughening downwards.	
358 + cms	Blue/black, silty sand.	
BH 140	12.6 m O.D.	NS 6491 9955
0 - 69 cms	Carse.	
69 - 80 cms	Peat.	
80 - 90 cms	Grey sand.	
90 + cms	Rock or gravel(?).	
BH 141	12.2 m O.D.	NS 6492 9956
0 - 70 cms	Sandy carse.	
70 + cms	Rock(?).	
BH 142	12.8 m O.D.	NS 6491 9955
0 - 501 cms	Carse.	
501 + cms	Blue/black, sandy gravel.	
BH 143	13.1 m O.D.	NS 6491 9952
0 - 557 cms	Carse.	
557 + cms	Dark blue/black, coarse sand with some red (O.R.S.?) fragments.	
BH 144	13.3 m O.D.	NS 6489 9949
0 - 585 cms	Carse, becoming very black downwards.	
585 + cms	Coarse, black, sandy gravel.	
BH 145	13.2 m O.D.	NS 6489 9946
0 - 561 cms	Carse, with some sandy streaks near base.	
561 + cms	Gravel(?).	
BH 146	13.3 m O.D.	NS 6489 9945
0 - 308 cms	Carse.	
308 - 368 cms	Peat.	
368 + cms	Grey, silty sand, slightly green in places.	

BH 147	13.5 m O.D.	NS 6489 9942
0 - 286 cms	Carse.	
286 - 356 cms	Peat with large, woody fragments near base.	
356 + cms	Grey, silty sand.	
BH 148	13.3 m O.D.	NS 6489 9934
0 - 270 cms	Carse.	
270 - 352 cms	Peat.	
352 + cms	Grey, silty sand.	
BH 149	13.5 m O.D.	NS 6489 9922
0 - 348 cms	Carse.	
348 - 425 cms	Peat.	
425 + cms	Grey, silty sand.	
BH 150	13.4 m O.D.	NS 6491 9915
0 - 284 cms	Carse.	
284 - 388 cms	Peat. Quite woody near base.	
388 + cms	Grey, silty clay becoming more sandy with depth.	
BH 151	13.7 m O.D.	NS 6491 9907
0 - 259 cms	Carse.	
259 - 366 cms	Peat, woody near base.	
366 + cms	Grey, silty sand.	
BH 152	13.7 m O.D.	NS 6492 9891
0 - 244 cms	Carse.	
244 - 365 cms	Peat.	
365 + cms	Grey, silty clay.	
BH 153	14.9 m O.D.	NS 6491 9878
0 - 123 cms	Moss peat.	
123 - 377 cms	Carse.	
377 - 491 cms	Peat.	
491 + cms	Grey, silty sand.	
BH 154	15.2 m O.D.	NS 6491 9868
0 - 111 cms	Moss peat.	
111 - 394 cms	Carse.	
394 - 512 cms	Peat.	
512 + cms	Grey, silty sand.	
BH 155	16.3 m O.D.	NS 6491 9864
0 - 233 cms	Moss peat, wood at base.	
233 - 547 cms	Carse.	
547 - 649 cms	Peat.	
649 + cms	Grey, silty sand.	
BH 156	18.2 m O.D.	NS 6491 9848
0 - 428 cms	Moss peat.	
428 - 778 cms	Carse.	
778 - 860 cms	Peat, very dark with fragments of reeds.	
860 + cms	Grey, silty sand.	

BH 157	17.9 m O.D.	NS 6491 9829
0 - 388 cms	Moss peat, woody near base.	
388 - 743 cms	Carse.	
743 - 819 cms	Peat.	
819 + cms	Grey, silty sand.	

BH 158	17.8 m O.D.	NS 6502 9818
0 - 378 cms	Moss peat, slightly woody at base.	
378 - 782 cms	Carse.	
782 - 850 cms	Peat.	
850 + cms	Grey, silty clay with sand.	

BH 159	17.8 m O.D.	NS 6507 9801
0 - 378 cms	Moss peat.	
378 - 809 cms	Carse.	
809 - 840 cms	Peat, piece of tree near top.	
840 + cms	Grey, slightly green, silty sand.	

BH 160	16.8 m O.D.	NS 6509 9795
0 - 295 cms	Moss peat.	
295 - 788 cms	Carse.	
788 + cms	Grey, silty sand.	

BH 161	14.5 m O.D.	NS 6512 9793
0 - 49 cms	Moss peat.	
49 - 524 cms	Carse, shell fragments in lowest 6 cms.	
524 + cms	Grey, silty sand.	

BH 162	14.1 m O.D.	NS 6505 9779
0 - 442 cms	Carse, slightly peaty in top 5-10 cms.	
442 - 463 cms	Peat.	
463 + cms	Grey, silty sand.	

BH 163	13.4 m O.D.	NS 6505 9767
0 - 492 cms	Carse.	
492 - 547 cms	Peat, very woody near base.	
547 - 563 cms	Peat/clay/silty sand mixture.	
563 + cms	Grey, silty sand.	

BH 164	13.6 m O.D.	NS 6511 9762
0 - 561 cms	Carse.	
561 - 615 cms	Peat, very tough and woody.	
615 - 627 cms	Grey clay.	
627 + cms	Grey, silty sand with a considerable proportion of clay.	

BH 165	13.6 m O.D.	NS 6508 9751
0 - 544 cms	Carse.	
544 - 595 cms	Peat, quite woody at top.	
595 + cms	Grey, silty sand with clay in top 10 cms.	

BH 166	13.5 m O.D.	NS 6509 9743
0 - 690 cms	Carse. Shell bed between 663-675 cms.	
690 + cms	Dark grey, tough, shelly sand.	

BH 167	13.6 m O.D.	NS 6508 9746
0 - 751 cms	Carse.	
751 + cms	Grey, silty sand.	
BH 168	13.6 m O.D.	NS 6508 9748
0 - 698 cms	Carse.	
698 + cms	Grey, silty sand.	
BH 169	13.5 m O.D.	NS 6508 9749
0 - 557 cms	Carse.	
557 - 604 cms	Peat, mixed with clay or fine sand beyond 568 cms.	
604 + cms	Grey, silty clay.	
BH 170	13.3 m O.D.	NS 6503 9732
0 - 543 cms	Carse.	
543 + cms	Peat(?).	
BH 171	13.2 m O.D.	NS 6504 9729
0 - 528 cms	Carse. Very sandy in places especially near the base.	
528 - 553 cms	Very tough peat.	
553 + cms	Grey clay.	
BH 172	13.1 m O.D.	NS 6505 9725
0 - 539 cms	Carse. Very sandy near base.	
539 - 563 cms	Peat.	
563 + cms	Grey clay. Vegetable matter in top 3-5 cms.	
BH 173	13.1 m O.D.	NS 6505 9721
0 - 532 cms	Carse. Quite sandy near base.	
532 - 548 cms	Peat.	
548 + cms	Grey clay.	
BH 174	12.9 m O.D.	NS 6508 9712
0 - 500+ cms	Tough carse.	
BH 175	12.9 m O.D.	NS 6508 9716
0 - 535 cms	Carse.	
535 - 547 cms	Peat.	
547 + cms	Grey clay.	
BH 176	13.0 m O.D.	NS 6508 9717
0 - 539 cms	Carse. Quite sandy immediately above peat.	
539 - 549 cms	Peat.	
549 + cms	Grey clay with clay/peat mixture in top 2-3 cms.	
BH 177	12.8 m O.D.	NS 6511 9707
0 - 560+ cms	Tough carse.	
BH 178	12.6 m O.D.	NS 6514 9696
0 - 432+ cms	Carse. Alternating tough and soft layers.	
BH 179	8.6 m O.D.	NS 6514 9686
0 - 278+ cms	Carse, mixed in top metre with brown sand.	

BH 180 8.3 m O.D. NS 6537 9694

0 - 200+ cms Carse with brown sand on top.

BH 181 14.9 m O.D. NS 7149 9853

0 - 45 cms Brown sand.
45 + cms Pink and brown, weathered rock.

BH 182 14.8 m O.D. NS 7148 9852

0 - 100+ cms Pink sand mixed with clay in top 20 cms.

BH 183 14.6 m O.D. NS 7147 9849

0 - 100+ cms Pink sand mixed with clay.

BH 184 13.8 m O.D. NS 7146 9847

0 - 112 cms Carse.
112 + cms Pinkish sand and gravel.

BH 185 14.4 m O.D. NS 7148 9849

0 - 45 cms Carse.
45 + cms Reddish sand and gravel.

BH 186 13.4 m O.D. NS 7146 9846

0 - 165 cms Carse.
165 - 288 cms Peat, dark at top becoming lighter and tougher downwards.
288 + cms Light grey, silty sand. Very micaceous.

BH 187 13.5 m O.D. NS 7145 9845

0 - 215 cms Carse.
215 - 248 cms Peat.
248 - 264 cms Peat/clay mixture.
264 + cms Grey and pink sand and gravel.

BH 188 13.2 m O.D. NS 7144 9842

0 - 135 cms Carse.
135 - 151 cms Carse with layers of peat 3-5 cms thick.
151 - 291 cms Woody peat.
291 + cms Light grey/green, silty sand.

BH 189 12.5 m O.D. NS 7142 9839

0 - c100 cms Carse.
100 - 232 cms Peat.
232 + cms Light grey/green, silty sand.

BH 190 12.8 m O.D. NS 7139 9834

0 - 126 cms Carse.
126 - 149 cms Carse with thin layers of peat.
149 - 269 cms Peat, woody at top.
269 + cms Light grey/green, silty sand.

BH 191 12.7 m O.D. NS 7137 9827

0 - 135 cms Carse.
135 - 284 cms Peat, very woody in places.
284 + cms Light grey/green, silty sand.

BH 192	12.6 m O.D.	NS 7132 9819
0 - 203 cms	Carse.	
203 - 320 cms	Peat.	
320 + cms	Light grey/green, silty sand, with clay in top 20 cms.	

BH 193	12.6 m O.D.	NS 7129 9811
0 - 227 cms	Carse.	
227 - 315 cms	Peat, woody at top.	
315 + cms	Light grey/green, silty sand. Clay at top.	

BH 194	12.3 m O.D.	NS 7128 9802
0 - 291 cms	Carse.	
291 - 356 cms	Peat.	
356 + cms	Grey/green, silty sand. Top 10-15 cms contain high proportion of clay.	

BH 195	12.6 m O.D.	NS 7121 9792
0 - 346 cms	Carse.	
346 - 407 cms	Peat.	
407 + cms	Light grey, silty clay, sandy with depth.	

BH 196	12.5 m O.D.	NS 7122 9797
0 - 337 cms	Carse.	
337 - 389 cms	Peat.	
389 + cms	Light grey (green) silty clay.	

BH 197	12.6 m O.D.	NS 7118 9786
0 - 368 cms	Carse.	
368 - 397 cms	Peat.	
397 + cms	Light grey, silty clay becoming coarser downwards.	

BH 198	12.4 m O.D.	NS 7113 9778
0 - 358 cms	Carse.	
358 - 391 cms	Peat.	
391 + cms	Light grey, silty clay.	

BH 199	12.5 m O.D.	NS 7109 9769
0 - 387 cms	Carse.	
387 - 416 cms	Peat. Tough and woody at top.	
416 + cms	Greenish/grey, silty clay, tending to coarsen downwards.	

BH 200	12.4 m O.D.	NS 7105 9762
0 - 403 cms	Carse.	
403 - 437 cms	Grey, slightly green, silty sand.	
437 + cms	Pinkish/grey sand.	

BH 201	12.5 m O.D.	NS 7108 9765
0 - 392 cms	Carse.	
392 - 404 cms	Peat. Tough and woody at top.	
404 - 467 cms	Light grey, silty sand.	
467 + cms	Grey/brown, silty sand.	

BH 202	12.5 m O.D.	NS 7105 9756
0 - 460 cms	Carse.	
460 + cms	Pinkish/grey, silty sand.	
BH 203	12.0 m O.D.	NS 7105 9752
0 - 448 cms	Tough carse.	
448 + cms	Dark grey, silty sand.	
BH 204	12.1 m O.D.	NS 7107 9748
0 - 489 cms	Carse.	
489 + cms	Dark grey, silty sand.	
BH 205	12.1 m O.D.	NS 7109 9742
0 - 543 cms	Carse.	
543 + cms	Greyish/brown, silty sand.	
BH 206	12.0 m O.D.	NS 7111 9736
0 - 624 cms	Carse.	
624 + cms	Tough, grey, silty sand.	
BH 207	12.6 m O.D.	NS 7113 9728
0 - 712 cms	Carse. Layers of sand beneath 500 cms.	
712 + cms	Tough, grey sand.	
BH 208	12.6 m O.D.	NS 7115 9722
0 - 438 cms	Carse.	
438 + cms	Dark grey, silty sand.	
BH 209	12.6 m O.D.	NS 7116 9716
0 - 417 cms	Carse.	
417 + cms	Dark grey, sandy silt.	
BH 210	12.5 m O.D.	NS 7119 9709
0 - 444 cms	Carse.	
444 + cms	Dark grey/blue, silty sand.	
BH 211	12.3 m O.D.	NS 7121 9702
0 - 506 cms	Carse.	
506 + cms	Dark grey, silty sand.	
BH 212	12.6 m O.D.	NS 7115 9725
0 - 500+ cms	Tough, sandy carse.	
BH 213	Not Levelled	NS 7125 9691
0 - 570+ cms	Carse. Becomes tougher downwards. Merges with grey sand between 560 and 570 cms.	
BH 214	Not Levelled	NS 7128 9682
0 - 450+ cms	Carse. Dark blue/black with thin bands of sand.	
BH 215	Not Levelled	NS 7132 9667
0 - 647+ cms	Carse. Tough, blue/black clay with bands of sand.	

BH 216		Not Levelled	NS 7138 9651
0 - 477+ cms	Carse. Dark blue and sandy. Some shell fragments.		
BH 217		Not Levelled	NS 7141 9641
0 - 550+ cms	Carse. Tough, dark blue, sandy sediments.		
BH 218		10.8 m O.D.	NS 7155 9641
0 - 505+ cms	Carse. Shell-bed -- 439-445 cms. Easily recognisable as *Cardium*. Both values complete in some cases. Quite small (2 cms). Bands of sand begin to appear below the shell-bed and deposit toughens.		
BH 219		10.5 m O.D.	NS 7164 9590
0 - 700+ cms	Carse. Coarser with depth.		
BH 220		10.5 m O.D.	NS 7154 9530
0 - 550+ cms	Carse. Sandier with depth.		
BH 221		10.6 m O.D.	NS 7158 9641
0 - 490+ cms	Carse. Dark blue, tough carse, with occasional shells.		
BH 222		12.9 m O.D.	NS 7188 9841
0 - 235 cms	Carse. Mixed with peat near base.		
235 - 277 cms	Peat.		
277 + cms	Grey, silty sand.		
BH 223		12.4 m O.D.	NS 7188 9783
0 - 379 cms	Carse.		
379 + cms	Grey sand.		
BH 224		11.9 m O.D.	NS 7180 9716
0 - 635 cms	Carse.		
635 + cms	Coarse sand and gravel.		
BH 225		11.2 m O.D.	NS 7172 9650
0 - 561 cms	Carse.		
561 + cms	Coarse sand.		
BH 226		13.4 m O.D.	NS 7318 9822
0 - 92 cms	Carse.		
92 + cms	Gravel.		
BH 227		14.1 m O.D.	NS 7284 9843
0 - 150 cms	Carse.		
150 + cms	Gravel.		
BH 228		12.3 m O.D.	NS 7327 9821
0 - 110 cms	Carse.		
110 + cms	Gravel.		
BH 229		12.3 m O.D.	NS 7337 9816
0 - 105 cms	Carse.		
105 + cms	Gravel.		

BH 230		12.0 m O.D.	NS 7386 9691
0 - 174 cms	Moss peat.		
174 - 550 cms	Carse.		
550 + cms	Gravel.		
BH 231		10.8 m O.D.	NS 7167 9643
0 - 586+ cms	Carse. Very tough near base.		
BH 232		10.3 m O.D.	NS 7169 9647
0 - 547+ cms	Carse. Boring stopped by blue/black clay alternating with very thin bands of sand.		
BH 233		10.6 m O.D.	NS 7171 9651
0 - 532+ cms	Tough carse.		
BH 234		11.2 m O.D.	NS 7173 9657
0 - 356+ cms	Tough, blue/black carse.		
BH 235		10.9 m O.D.	NS 7175 9641
0 - 479+ cms	Tough, blue/black carse.		
BH 236		9.5 m O.D.	NS 7175 9639
0 - 295+ cms	Tough, blue/black carse.		
BH 237		11.5 m O.D.	NS 7179 9659
0 - 600 cms	Carse. Thin, sandy bands with shell fragments near base.		
600 + cms	Clay with sand and small gravel.		
BH 238		11.4 m O.D.	NS 7177 9661
0 - 575+ cms	Tough, blue/black carse.		
BH 239		11.5 m O.D.	NS 7187 9658
0 - 614 cms	Carse, with thin bands of sand and shell fragments in bottom 10-15 cms.		
614 + cms	Coarse, brown/grey sand.		
BH 240		11.4 m O.D.	NS 7195 9655
0 - 534+ cms	Tough, black carse.		
BH 241		11.7 m O.D.	NS 7199 9668
0 - 531+ cms	Tough, blue/black carse.		
BH 242		11.9 m O.D.	NS 7207 9664
0 - 405+ cms	Carse. Increasingly tough and sandy with depth.		
BH 243		11.8 m O.D.	NS 7213 9682
0 - 343+ cms	Tough carse.		
BH 244		11.8 m O.D.	NS 7198 9688
0 - 116 cms	Carse.		
116 - 126 cms	Hard, black, wood fragments.		
126 - 450 cms	Carse. Becoming sandier at c.440 cms.		
450 + cms	Coarse, brown/grey sand.		

BH 245		11.3 m O.D.	NS 7415 9737
0 - 179 cms	Carse.		
179 + cms	Red sand and gravel probably associated with Nyadd rock.		
BH 246		11.1 m O.D.	NS 7421 9735
0 - 191 cms	Very tough carse.		
191 - 205 cms	Sand and small gravel.		
205 - 209 cms	Grey clay with some vegetable fragments.		
209 + cms	Coarse sand and gravel.		
BH 247		10.6 m O.D.	NS 7433 9732
0 - 144 cms	Carse.		
144 - 180 cms	Coarse sand and small gravel.		
180 - 200 cms	Grey clay with vegetable fragments.		
200 + cms	Gravel, quartz rich and quite angular.		
BH 248		10.9 m O.D.	NS 7432 9729
0 - 184 cms	Carse.		
184 + cms	Coarse sand and gravel.		
BH 249		11.9 m O.D.	NS 7412 9734
0 - 79 cms	Carse - mixed with pink sand from rock especially in bottom 10-20 cms.		
79 + cms	Rock.		
BH 250		11.5 m O.D.	NS 7413 9736
0 - 126 cms	Carse.		
126 - 138 cms	Carse and bands of red, micaceous sand.		
138 + cms	Rock - very thin band of coarse sand on top.		
BH 251		10.5 m O.D.	NS 7409 9728
0 - 220 cms	Carse.		
220 + cms	Rock.		
BH 252		11.2 m O.D.	NS 7407 9724
0 - 286 cms	Carse.		
286 - 294 cms	Grey, sandy clay.		
294 + cms	Coarse sand and gravel.		
BH 253		11.0 m O.D.	NS 7403 9716
0 - 281 cms	Carse, becoming coarser near base.		
281 + cms	Coarse sand and gravel.		
BH 254		11.2 m O.D.	NS 7398 9707
0 - 327 cms	Carse, becoming coarser near base.		
327 + cms	Gravel.		
BH 255		11.6 m O.D.	NS 7392 9701
0 - 22 cms	Moss peat.		
22 - 398 cms	Carse.		
398 - 427 cms	Dark, grey sand.		
427 + cms	Coarse sand and gravel.		

BH 256	12.1 m O.D.	NS 7386 9694
0 - 117 cms	Moss peat.	
117 - 514 cms	Carse, quite sandy in bottom 20-30 cms.	
514 + cms	Gravel.	

BH 257	10.7 m O.D.	NS 7433 9731
0 - 188 cms	Very tough carse.	
188 + cms	Coarse sand.	

BH 258	10.7 m O.D.	NS 7436 9739
0 - 146 cms	Very tough carse.	
146 - 155 cms	Coarse sand and small gravel.	
155 - 195 cms	Blue/grey, silty sand with considerable vegetable matter in top 5-10 cms.	
195 + cms	Small gravel.	

BH 259	10.6 m O.D.	NS 7448 9743
0 - 178 cms	Carse with red and brown staining throughout.	
178 + cms	Coarse sand and gravel.	

BH 260	11.0 m O.D.	NS 7439 9748
0 - 173 cms	Very tough carse.	
173 - 192 cms	Coarse, weathered sand.	
192 - 233 cms	Grey clay, becoming sandier with depth.	
233 + cms	Gravel.	

BH 261	11.0 m O.D.	NS 7443 9755
0 - 166 cms	Very tough carse.	
166 - 172 cms	Gravel with some O.R.S. fragments.	
172 - 225 cms	Grey/brown clay, becoming coarser with depth.	
225 + cms	Gravel.	

BH 262	11.0 m O.D.	NS 7447 9763
0 - 229 cms	Carse, very sandy near base.	
229 + cms	Gravel.	

BH 263	9.8 m O.D.	NS 7448 9769
0 - 100 cms	Carse, very sandy near base.	
100 + cms	Gravel.	

BH 264	11.4 m O.D.	NS 7457 9788
0 - 101 cms	Carse.	
101 - 110 cms	Gravel.	
110 - 141 cms	Carse.	
141 + cms	Red sand and gravel.	

BH 265	11.3 m O.D.	NS 7464 9804
0 - 74 cms	Carse.	
74 - 81 cms	Gravel.	
81 - 96 cms	Carse.	
96 - 113 cms	Tough, grey, silty sand.	
113 - 386 cms	Light grey clay.	
386 + cms	Gravel.	

BH 266		11.3 m O.D.	NS 7461 9799
0 - 98 cms	Carse.		
98 - 105 cms	Gravel.		
105 - 374 cms	Carse.		
374 + cms	Coarse sand and gravel.		
BH 267		11.2 m O.D.	NS 7458 9794
0 - 95 cms	Carse.		
95 - 112 cms	Coarse sand and big gravel.		
112 - 229 cms	Carse.		
229 + cms	Coarse, grey sand and gravel.		
BH 268		11.1 m O.D.	NS 7465 9809
0 - 50 cms	Carse.		
50 - 83 cms	Coarse sand and gravel.		
83 - 443 cms	Carse.		
443 + cms	Dark grey/black, coarse sand.		
BH 269		11.1 m O.D.	NS 7471 9811
0 - 386 cms	Carse - darker near base and including vegetable fragments.		
386 + cms	Coarse sand and gravel.		
BH 270		11.3 m O.D.	NS 7478 9821
0 - 316 cms	Carse, including peat fragments and 2-3 cms of peaty sand near base.		
316 + cms	Coarse sand and gravel.		
BH 271		10.0 m O.D.	NS 7481 9826
0 - 234 cms	Carse.		
234 + cms	Coarse, pink sand and gravel.		
BH 272		9.9 m O.D.	NS 7481 9827
0 - 316 cms	Carse with layers of sand and a peaty band at base.		
316 + cms	Coarse sand and gravel.		
BH 273		9.9 m O.D.	NS 7483 9828
0 - 90 cms	Carse. Sandy in places.		
90 + cms	Gravel.		
BH 274		9.9 m O.D.	NS 7485 9832
0 - 86 cms	Carse, with bands of red sand.		
86 + cms	Coarse, red sand and gravel.		
BH 275		9.9 m O.D.	NS 7486 9834
0 - 85 cms	Carse with bands of red sand.		
85 + cms	Big gravel, overlain by red sand.		
BH 276		9.8 m O.D.	NS 7488 9838
0 - 78 cms	Carse with bands of red sand.		
78 + cms	Gravel.		

BH 277		12.1 m O.D.	NS 7383 9686
0 - 91 cms	Peat. Peat/carse mixture near base.		
91 - 542 cms	Carse. Very sandy near base.		
542 + cms	Coarse, grey sand and gravel.		
BH 278		11.3 m O.D.	NS 7379 9679
0 - 492 cms	Carse. Very sandy and shelly at base.		
492 + cms	Coarse sand and gravel.		
BH 279		11.3 m O.D.	NS 7375 9672
0 - 499 cms	Carse. Very sandy and shelly near base. Shell fragments perhaps *Ostrea* or *Mytilus*.		
499 + cms	Coarse, grey sand and gravel.		
BH 280		11.2 m O.D.	NS 7372 9664
0 - 503 cms	Carse. Sandy and shelly near base.		
503 + cms	Coarse sand and gravel.		
BH 281		10.4 m O.D	NS 7368 9657
0 - 448 cms	Carse. Very sandy and shelly in bottom 20-30 cms. Shells perhaps *Ostrea* or *Mytilus*.		
448 + cms	Coarse sand and gravel.		
BH 282		10.4 m O.D.	NS 7366 9653
0 - 443 cms	Carse. Very sandy and shelly at base.		
443 + cms	Gravel. Some thin peat on top.		
BH 283		10.2 m O.D.	NS 7357 9654
0 - 400 cms	Carse. Very sandy near base.		
400 + cms	Coarse sand and gravel.		
BH 284		11.2 m O.D.	NS 7352 9647
0 - 550 cms	Very tough carse.		
550 + cms	Dark grey sand.		
BH 285		11.2 m O.D.	NS 7352 9641
0 - 594 cms	Carse.		
594 + cms	Coarse, tough, dark grey sand.		
BH 286		8.2 m O.D.	NS 7338 9618
0 - 345 cms	Carse. Sand and some shell fragments near base.		
345 + cms	Coarse sand and gravel.		
BH 287		6.7 m O.D.	NS 7328 9606
0 - 104 cms	Carse. Red and sandy in top 20 cms.		
104 - 158 cms	Slightly woody peat.		
158 - 191 cms	Grey, silty clay.		
191 + cms	Light grey, tough, fine sand.		
BH 288		8.7 m O.D.	NS 7327 9606
0 - 335 cms	Carse. Shells at base.		
335 + cms	Light grey sand.		

BH 289		7.5 m O.D.	NS 7329 9610
0 - 87	cms	Carse.	
87 - 104	cms	Peat.	
104 - 364	cms	Grey clay.	
364 - 379	cms	Peat in two bands separated by 2.0 cms of clay.	
379 +	cms	Coarse, pinkish/grey sand.	
BH 290		6.5 m O.D.	NS 7329 9604
0 - 73	cms	Carse. Red and sandy at top.	
73 - 212	cms	Peat, mixed with clay from c.190 cms.	
212 - 300	cms	Grey, silty clay. Becoming coarser downwards.	
300 +	cms	Coarse, grey sand and small gravel.	
BH 291		9.2 m O.D.	NS 7324 9594
0 - 392	cms	Carse. Very sandy near base.	
392 +	cms	Boring stopped by coarse, grey sand.	
BH 292		10.4 m O.D.	NS 7675 9582
0 - 408	cms	Carse, with thin layers of shelly sand from 375 cms downwards.	
408 +	cms	Light grey, coarse sand.	
BH 293		10.5 m O.D.	NS 7672 9578
0 - 415	cms	Carse, with thin bands of shelly sand from c.360 cms.	
415 +	cms	Pink/grey, coarse sand with rock(?) beneath.	
BH 294		10.5 m O.D.	NS 7669 9575
0 - 315	cms	Carse.	
315 - 336	cms	Peat.	
336 - 352	cms	Grey/green, silty clay.	
352 +	cms	Grey/green, silty sand.	
BH 295		10.3 m O.D.	NS 7671 9577
0 - 319	cms	Carse. Shell fragments at base.	
319 - 327	cms	Peat.	
327 - 349	cms	Grey/green, silty clay.	
349 +	cms	Grey/green, silty sand.	
BH 296		10.4 m O.D.	NS 7671 9578
0 - 384	cms	Carse.	
384 +	cms	Pinkish/grey, coarse sand.	
BH 297		10.3 m O.D.	NS 7671 9578
0 - 316	cms	Carse, shell fragments at base.	
316 - 327	cms	Peat.	
327 - 346	cms	Grey/green, silty clay.	
346 +	cms	Grey/green, silty sand.	
BH 298		10.5 m O.D.	NS 7667 9574
0 - 301	cms	Carse.	
301 - 304	cms	Peat.	
304 - 311	cms	Grey, silty clay. Sandy near base.	
311 +	cms	Orange/red, silty sand.	

BH 299		10.6 m O.D.	NS 7666 9572
0 - 294 cms	Carse.		
294 - 308 cms	Slightly woody peat.		
308 - 336 cms	Grey, silty clay. Slightly sandy in top 2.0 cms and near base.		
336 + cms	Red sand.		
BH 300		11.5 m O.D.	NS 7664 9569
0 - 23 cms	Red sand and clay.		
23 + cms	Rock.		
BH 301		10.7 m O.D.	NS 7665 9571
0 - 292 cms	Carse, stained red and sandy near top.		
292 - 297 cms	Transition zone.		
297 - 309 cms	Peat.		
309 - 339 cms	Grey/green, silty clay.		
339 + cms	Orange/red sand, very tough.		
BH 302		9.9 m O.D.	NS 7678 9577
0 - 346 cms	Carse. Shell fragments at base.		
346 + cms	Coarse, grey sand.		
BH 303		8.0 m O.D.	NS 7685 9571
0 - 119 cms	Carse.		
119 - 140 cms	Transition zone.		
140 + cms	Grey sand.		
BH 304		8.5 m O.D.	NS 7692 9564
0 - 109 cms	Carse.		
109 - 127 cms	Transition zone.		
127 + cms	Grey sand.		
BH 305		9.4 m O.D.	NS 7691 9559
0 - 321 cms	Tough carse.		
321 + cms	Mixed pink, grey and black sand.		
BH 306		10.0 m O.D.	NS 7687 9558
0 - 234 cms	Carse.		
234 - 246 cms	Peat.		
246 - 262 cms	Grey, silty clay.		
262 + cms	Grey, silty sand.		
BH 307		10.3 m O.D.	NS 7682 9557
0 - 260 cms	Carse.		
260 - 271 cms	Peat.		
271 - 283 cms	Grey/green, silty clay.		
283 + cms	Grey/green, silty sand.		
BH 308		10.3 m O.D.	NS 7679 9556
0 - 240 cms	Carse.		
240 - 244 cms	Transition zone.		
244 - 256 cms	Peat.		
256 - 268 cms	Grey/green, silty clay.		
268 + cms	Grey/green, silty sand.		

BH 309		8.9 m O.D.	NS 7691 9561
0 - 133	cms	Carse. Quite sandy in places.	
133 - 135	cms	Peat.	
135 - 163	cms	Mixture of clay and sand.	
163 +	cms	Coarse, grey sand.	
BH 310		9.3 m O.D.	NS 7691 9559
0 - 160	cms	Carse.	
160 - 165	cms	Transition zone.	
165 - 169	cms	Peat.	
169 +	cms	Grey, silty sand.	
BH 311		9.8 m O.D.	NS 7688 9558
0 - 204	cms	Carse.	
204 - 208	cms	Slightly woody peat.	
208 +	cms	Grey, silty sand.	
BH 312		10.4 m O.D.	NS 7677 9556
0 - 232	cms	Very sandy carse.	
232 - 248	cms	Peat.	
248 - 267	cms	Grey/green, silty clay.	
267 - 272	cms	Grey, silty sand.	
272 +	cms	Red sand.	
BH 313		10.8 m O.D.	NS 7678 9556
0 - 54	cms	Red sand.	
54 +	cms	Red/brown clay.	
BH 314		11.2 m O.D.	NS 7678 9556
0 - 47	cms	Red sand and clay with stones.	
47 +	cms	Rock.	
BH 315		7.9 m O.D.	NS 7664 9594
0 - 272	cms	Carse.	
272 - 331	cms	Black, shelly *(Cardium)*, sand.	
331 +	cms	Rock or perhaps big gravel. Sample taken.	
BH 316		9.2 m O.D.	NS 7661 9591
0 - 355	cms	Carse.	
355 +	cms	Black, shelly sand.	
BH 317		9.8 m O.D.	NS 7655 9585
0 - 267	cms	Carse.	
267 +	cms	Rock or big gravel.	
BH 318		9.8 m O.D.	NS 7648 9579
0 - 268	cms	Carse.	
268 - 285	cms	Peat.	
285 - 329	cms	Grey, silty sand with some clay at top.	
329 +	cms	Very coarse, grey sand.	
BH 319		9.9 m O.D.	NS 7652 9584
0 - 223	cms	Carse. Shelly fragments at base.	
223 +	cms	Red and grey, shelly sand.	

BH 320	9.8 m O.D.	NS 7649 9581
0 - 228 cms	Carse.	
228 - 265 cms	Grey, shelly clay (carse?) with red sand in top few cms.	
265 - 272 cms	Peat.	
272 + cms	Grey, silty sand.	

BH 321	9.8 m O.D.	NS 7651 9582
0 - 208 cms	Carse.	
208 + cms	Rock, overlain by a thin band of red, shelly sand.	

BH 322	9.4 m O.D.	NS 7644 9575
0 - 103 cms	Carse.	
103 - 121 cms	Shelly clay.	
121 - 146 cms	Carse.	
146 - 164 cms	Peat.	
164 - 273 cms	Grey/blue, silty clay.	
273 - 285 cms	Brown/grey sand.	
285 + cms	Rock.	

BH 323	9.8 m O.D.	NS 7642 9572
0 - 129 cms	Carse.	
129 - 171 cms	Clay/peat mixture.	
171 - 215 cms	Grey, silty clay.	
215 - 230 cms	Peat.	
230 - 236 cms	Grey, silty sand.	
236 + cms	Pink, silty clay.	

BH 324	9.8 m O.D.	NS 7642 9572
0 - 152 cms	Carse with red sand.	
152 - 177 cms	Clay/peat mixture.	
177 - 225 cms	Grey/blue, silty clay.	
225 - 247 cms	Peat.	
247 - 258 cms	Grey, silty clay becoming sandier downwards.	
258 - 262 cms	Red, silty sand.	
262 + cms	Rock.	

BH 325	9.6 m O.D.	NS 7641 9569
0 - 88 cms	Carse.	
88 - 139 cms	Peat (dark brown).	
139 - 206 cms	Grey, silty clay (carse?).	
206 - 220 cms	Peat (light brown).	
220 - 244 cms	Grey, silty clay merging with grey sand at c.229 cms.	
244 + cms	Rock.	

BH 326	7.2 m O.D.	NS 7665 9595
0 - 173 cms	Carse.	
173 - 258 cms	Shelly clay.	
258 + cms	Coarse, grey sand.	

BH 327	7.8 m O.D.	NS 7668 9599
0 - 342 cms	Carse.	
342 + cms	Rock, or big gravel.	

BH 328		7.8 m O.D.	NS 7667 9597
0 - 337	cms	Carse. Becoming sandier downwards and with thin layer of shells at the base.	
337 +	cms	Coarse, grey sand.	
BH 329		7.3 m O.D.	NS 7672 9604
0 - 232	cms	Carse.	
232 +	cms	Rock.	
BH 330		6.7 m O.D.	NS 7676 9611
0 - 214	cms	Carse. Includes shell fragments *(Ostrea?)*.	
214 +	cms	Gravel.	
BH 331		6.7 m O.D.	NS 7679 9618
0 - 370	cms	Tough carse.	
370 +	cms	Gravel.	
BH 332		6.8 m O.D.	NS 7677 9614
0 - 367	cms	Carse. Including some shell fragments.	
367 +	cms	Gravel.	
BH 333		5.8 m O.D.	NS 7682 9627
0 - 173	cms	Fine, red sand.	
173 +	cms	Coarse sand and small gravel.	
BH 334		5.7 m O.D.	NS 7681 9622
0 - 267	cms	Clay/sand mixture in top metre. Normal grey/blue carse below this.	
267 +	cms	Gravel.	
BH 335		9.9 m O.D.	NS 7643 9579
0 - 402	cms	Carse.	
402 +	cms	Rock.	
BH 336		10.4 m O.D.	NS 7637 9567
0 - 322	cms	Carse.	
322 - 335	cms	Peat.	
335 - 352	cms	Grey/green, silty clay.	
352 +	cms	Grey/green, silty sand.	
BH 337		10.5 m O.D.	NS 7639 9561
0 - 283	cms	Carse.	
283 - 292	cms	Peat.	
292 +	cms	Coarse, grey sand.	
BH 338		10.4 m O.D.	NS 7627 9562
0 - 295	cms	Carse.	
295 - 312	cms	Peat.	
312 +	cms	Grey/green, silty sand.	
BH 339		10.5 m O.D.	NS 7618 9556
0 - 463	cms	Carse. Increasingly sandy with depth.	
463 +	cms	Coarse sand and gravel.	

BH 340		10.5 m O.D.	NS 7625 9561
0 - 438	cms	Carse. Coarser and darker with depth.	
438 +	cms	Rock or big gravel.	
BH 341		10.3 m O.D.	NS 7629 9563
0 - 302	cms	Carse.	
302 - 319	cms	Peat.	
319 +	cms	Grey, silty sand.	
BH 342		10.6 m O.D.	NS 7614 9553
0 - 369	cms	Carse.	
369 - 381	cms	Peat.	
381 +	cms	Grey/green, silty sand.	
BH 343		10.3 m O.D.	NS 7618 9557
0 - 421	cms	Carse. Darker and sandier with depth.	
421 +	cms	Grey/brown, coarse sand.	
BH 344		10.5 m O.D.	NS 7611 9551
0 - 369	cms	Carse.	
369 +	cms	Grey/green, silty sand.	
BH 345		10.4 m O.D.	NS 7605 9547
0 - 322	cms	Carse.	
322 - 341	cms	Transition zone.	
341 - 374	cms	Grey/green, silty clay.	
374 +	cms	Grey/green, silty sand.	
BH 346		10.5 m O.D.	NS 7609 9541
0 - 342	cms	Carse. Some peat layers near base.	
342 - 351	cms	Peat.	
351 - 357	cms	Grey/green, silty clay.	
357 +	cms	Grey/green, silty sand.	
BH 347		10.8 m O.D.	NS 7627 9595
0 - 488	cms	Carse. Quite dark and sandy near base.	
488 +	cms	Rock or big gravel.	
BH 348		10.6 m O.D.	NS 7629 9596
0 - 483	cms	Carse.	
483 +	cms	Rock or big gravel.	
BH 349		10.5 m O.D.	NS 7632 9588
0 - 450	cms	Carse. Tougher with depth.	
450 +	cms	Rock.	
BH 350		9.2 m O.D.	NS 7641 9578
0 - 204	cms	Carse.	
204 - 220	cms	Peat.	
220 - 262	cms	Grey/green, silty clay. Becoming coarser with depth.	
262 +	cms	Grey/green, silty sand.	
BH 351		10.2 m O.D.	NS 7622 9567
0 - 441	cms	Carse. Becoming dark blue/black near base.	
441 +	cms	Rock.	

BH 352		10.8 m O.D.	NS 7625 9571
0 - 494	cms	Carse. Becoming tougher with depth.	
494 +	cms	Rock.	
BH 353		10.7 m O.D.	NS 7614 9564
0 - 437	cms	Carse.	
437 +	cms	Grey/brown sand.	
BH 354		10.8 m O.D.	NS 7599 9554
0 - 369	cms	Carse.	
369 - 383	cms	Peat.	
383 - 404	cms	Grey, silty clay.	
404 +	cms	Grey, silty sand.	
BH 355		10.0 m O.D.	NS 7651 9498
0 - 745	cms	Carse. Tougher and darker with depth.	
745 +	cms	Rock or big gravel.	
BH 356		10.2 m O.D.	NS 7643 9506
0 - 443	cms	Carse. Darker and tougher with depth. Shell fragments near base.	
443 +	cms	Rock or big gravel.	
BH 357		10.1 m O.D.	NS 7637 9512
0 - 377	cms	Carse. Very shelly from 377 - c.400 cms.	
377 - 400	cms	Shelly clay.	
400 - 407	cms	Carse.	
407 +	cms	Grey/brown sand.	
BH 358		10.4 m O.D.	NS 7631 9518
0 - 378	cms	Carse. Very shelly from 350 cms down.	
378 +	cms	Grey/brown sand.	
BH 359		10.4 m O.D.	NS 7621 9528
0 - 344	cms	Carse.	
344 - 357	cms	Peat. Mixed with clay.	
357 - 383	cms	Grey/green, silty sand with a considerable proportion of clay in top 10 cms.	
383 +	cms	Grey/brown sand.	
BH 360		10.4 m O.D.	NS 7624 9523
0 - 335	cms	Carse. Shell fragments at base.	
335 - 348	cms	Peat. Mixed with clay in part.	
348 - 372	cms	Grey/green, silty sand. Some clay in top 10-15 cms.	
372 +	cms	Grey/brown sand.	
BH 361		10.5 m O.D.	NS 7627 9521
0 - 351	cms	Carse. Very shelly near base.	
351 - 352	cms	Peat.	
352 - 359	cms	Grey, silty clay. Some shell fragments at top.	
359 - 367	cms	Grey/green, silty clay.	
367 +	cms	Grey/brown sand.	

BH 362 10.7 m O.D. NS 7628 9519
0 - 406 cms Carse. Becoming tougher and sandier with depth.
406 + cms Grey/brown sand.

BH 363 9.7 m O.D. NS 7658 9489
0 - 731 cms Carse. Becoming blue/black and slightly tougher with depth.
731 + cms Dark pink, clayey sand with some stones.

BH 364 10.3 m O.D. NS 7662 9482
0 - 550+ cms Tough, black carse.

BH 365 10.0 m O.D. NS 7666 9476
0 - 470+ cms Tough carse.

BH 366 8.0 m O.D. NS 7671 9469
0 - 270+ cms Tough carse. Increasingly sandy with depth.

BH 367 9.7 m O.D. NS 7668 9747
0 - 650+ cms Tough carse. Tougher and sandier with depth.

BH 368 9.8 m O.D. NS 7664 9739
0 - 500+ cms Tough carse. Tougher and sandier with depth.

BH 369 10.2 m O.D. NS 7654 9742
0 - 550+ cms Tough carse. Tougher and coarser with depth.

BH 370 9.8 m O.D. NS 7641 9732
0 - 650+ cms Very tough carse.

BH 371 7.4 m O.D. NS 7633 9728
0 - 398 cms Very tough carse.
398 + cms Gravel.

BH 372 10.0 m O.D. NS 7647 9719
0 - 460+ cms Very tough carse.

BH 373 9.3 m O.D. NS 7661 9731
0 - 410+ cms Very tough carse.

BH 374 Not Levelled NS 7714 9727
0 - 550+ cms Tough carse. Mixed with peat in top 50 cms.

BH 375 12.4 m O.D. NS 8179 9655
0 - 185 cms Very soft carse.
185 - 232 cms Soft, brown peat.
232 + cms Coarse, grey/brown sand.

BH 376 12.5 m O.D. NS 8181 9651
0 - 210 cms Very soft carse.
210 - 282 cms Peat.
282 + cms Orange/brown sand with small gravel.

BH 377	12.4 m O.D.	NS 8181 9641
0 - 222 cms	Carse. Some red sand in places but otherwise very soft.	
222 - 316 cms	Peat.	
316 - 322 cms	Grey/brown sand.	
322 + cms	Pink, silty sand.	
BH 378	12.4 m O.D.	NS 8179 9643
0 - 229 cms	Carse.	
229 - 315 cms	Peat.	
315 + cms	Grey/brown sand.	
BH 379	12.4 m O.D.	NS 8181 9634
0 - 314 cms	Carse. Quite sandy near base.	
314 - 424 cms	Peat. Very tough and woody. Mixed with grey clay near base.	
424 + cms	Pink, silty sand.	
BH 380	11.7 m O.D.	NS 8183 9627
0 - 180 cms	Carse.	
180 - 282 cms	Peat. Woody in places.	
282 - 290 cms	Brown sand.	
290 + cms	Pink clay. Slightly grey in top few cms.	
BH 381	11.6 m O.D.	NS 8185 9615
0 - 248 cms	Carse.	
248 - 320 cms	Peat.	
320 - 345 cms	Grey/green, silty sand.	
345 + cms	Pink clay.	
BH 382	11.9 m O.D.	NS 8183 9621
0 - 251 cms	Carse.	
251 - 343 cms	Peat. Woody on top.	
343 - 354 cms	Grey/green, silty clay. Very light in colour.	
354 + cms	Pink clay.	
BH 383	12.0 m O.D.	NS 8189 9611
0 - 309 cms	Carse.	
309 - 351 cms	Peat.	
351 - 362 cms	Light grey/green clay.	
362 - 373 cms	Pink clay.	
373 + cms	Reddish/pink sand.	
BH 384	12.1 m O.D.	NS 8191 9602
0 - 342 cms	Carse.	
342 - 356 cms	Peat.	
356 - 368 cms	Light grey/green clay.	
368 + cms	Pink clay.	
BH 385	12.0 m O.D.	NS 8194 9591
0 - 346 cms	Carse.	
346 - 368 cms	Peat.	
368 - 385 cms	Light grey/green, silty sand.	
385 + cms	Pink, silty sand.	

BH 386		11.3 m O.D.	NS 8198 9581
0 - 328 cms	Carse.		
328 - 336 cms	Peat.		
336 - 360 cms	Light grey/green, silty sand.		
360 + cms	Pink, silty sand.		
BH 387		10.8 m O.D.	NS 8199 9573
0 - 284 cms	Carse.		
284 - 296 cms	Peat.		
296 + cms	Light grey, silty sand.		
BH 388		10.4 m O.D.	NS 8202 9562
0 - 353 cms	Carse.		
353 - 382 cms	Very woody peat.		
382 - 417 cms	Light grey/green clay.		
417 + cms	Pink, silty sand. Quite clayey at top.		
BH 389		9.5 m O.D.	NS 8204 9548
0 - 324 cms	Carse.		
324 - 348 cms	Very tough peat.		
348 - 381 cms	Grey/green, silty sand.		
381 + cms	Pink, silty sand.		
BH 390		9.4 m O.D.	NS 8206 9541
0 - 372 cms	Carse.		
372 - 389 cms	Peat.		
389 + cms	Grey/green, silty sand.		
BH 391		9.6 m O.D.	NS 8205 9545
0 - 410 cms	Carse.		
410 - 432 cms	Peat.		
432 + cms	Grey/green, silty sand with clay on top.		
BH 392		9.3 m O.D.	NS 8208 9532
0 - 354 cms	Carse.		
354 - 367 cms	Peat.		
367 + cms	Grey, silty sand.		
BH 393		9.3 m O.D.	NS 8211 9524
0 - 502 cms	Carse. Very tough and sandy in places.		
502 - 504 cms	Peat.		
504 + cms	Grey, silty sand.		
BH 394		9.2 m O.D.	NS 8209 9528
0 - 355 cms	Carse.		
355 - 366 cms	Clay/peat mixture.		
366 - 378 cms	Grey, silty sand.		
378 + cms	Brown/pink, silty sand.		
BH 395		9.2 m O.D.	NS 8212 9519
0 - 346 cms	Carse.		
346 - 348 cms	Peat.		
348 + cms	Grey, silty sand. Slightly pink in top 5-10 cms.		

BH 396	8.4 m O.D.	NS 8214 9509
0 - 273 cms	Carse, very tough and sandy in places, black.	
273 + cms	Orange/red, silty sand. Peat at base. Still present at 315 cms where it is less orange and more grey.	
BH 397	8.9 m O.D.	NS 8213 9514
0 - 325 cms	Carse. Sandy and tough.	
325 - 327 cms	Clay/peat mixture.	
327 + cms	Very tough, grey/brown, silty sand.	
BH 398	5.9 m O.D.	NS 8213 9503
0 - 400+ cms	Carse. Contains layers of varying toughness.	
BH 399	4.4 m O.D.	NS 8207 9488
0 - 397 cms	Carse. Very soft at top but containing bands of fine sand which increase in frequency from c.300 cms and make penetration difficult beyond c.390 cms.	
397 + cms	Gravel.	
BH 400	4.8 m O.D.	NS 8205 9495
0 - 436 cms	Carse. Sandy from top but sandy nature and toughness increase downwards.	
436 + cms	Gravel.	
BH 401	4.6 m O.D.	NS 8214 9477
0 - 467 cms	Carse. Quite sandy in places.	
467 + cms	Grey/brown sand.	
BH 402	4.7 m O.D.	NS 8228 9471
0 - 450 cms	Carse.	
450 + cms	Grey/brown sand.	
BH 403	8.6 m O.D.	NS 8556 9601
0 - 70 cms	Fine sand.	
70 - 443 cms	Deposit still very sandy but containing clay which increases in proportion downwards.	
443 + cms	Gravel.	
BH 404	8.9 m O.D.	NS 8557 9595
0 - 156 cms	Carse. Tough and sandy.	
156 - 171 cms	Sand and small gravel.	
171 + cms	Pink, silty sand.	
BH 405	9.5 m O.D.	NS 8559 9592
0 - 93 cms	Carse. Quite sandy and very tough.	
93 + cms	Coarse, orange/red sand.	
BH 406	9.6 m O.D.	NS 8561 9588
0 - 70 cms	Carse. Very sandy and tough.	
70 - 93 cms	Coarse, orange/brown sand.	
93 + cms	Gravel.	
BH 407	9.5 m O.D.	NS 8558 9594
0 - 98 cms	Carse. Very tough and sandy.	
98 + cms	Coarse, red/brown sand and small gravel.	

BH 408		8.8 m O.D.	NS 8571 9596
0 - 55 cms	Fine sand.		
55 - 312 cms	Fine sand and clay.		
312 + cms	Gravel.		
BH 409		9.0 m O.D.	NS 8572 9593
0 - 61 cms	Mixture of sand and very little clay.		
61 + cms	Gravel.		
BH 410		9.6 m O.D.	NS 8574 9588
0 - 63 cms	Sand/clay mixture.		
63 + cms	Weathered orange and white sandstone, suggesting rock beneath.		
BH 411		12.6 m O.D.	NS 8521 9662
0 - 70 cms	Sandy carse.		
70 + cms	Grey sand, giving way to a mixture of grey and pink sand with small gravel.		
BH 412		12.0 m O.D.	NS 8522 9659
0 - 87 cms	Carse.		
87 + cms	Grey/brown sand and tightly packed gravel.		
BH 413		11.2 m O.D.	NS 8524 9651
0 - 20 cms	Sandy clay.		
20 + cms	Tough gravel.		
BH 414		11.1 m O.D.	NS 8525 9649
0 - 49 cms	Brown sand with surface clay.		
49 + cms	Tough gravel.		
BH 415		10.6 m O.D.	NS 8529 9644
0 - 95 cms	Red/brown sand with considerable proportion of clay and some stones at top.		
95 + cms	Coarse sand and gravel.		
BH 416		10.2 m O.D.	NS 8532 9639
0 - 72 cms	Red/brown sand with clay.		
72 - 172 cms	Carse-clay.		
172 - 176 cms	Peat.		
176 - 185 cms	Grey clay with some sand and small stones.		
185 + cms	Gravel and coarse, pink sand.		
BH 417		10.4 m O.D.	NS 8531 9641
0 - 68 cms	Red/brown, fine sand.		
68 + cms	Gravel.		
BH 418		10.3 m O.D.	NS 8531 9641
0 - 60 cms	Red/brown sand with some clay.		
60 - 177 cms	Light grey (carse) clay.		
177 - 181 cms	Peat.		
181 - 193 cms	Grey clay containing vegetable fragments and becoming sandier with depth.		
193 + cms	Gravel.		

BH 419	8.9 m O.D.	NS 8536 9629
0 - 102 cms	Grey/brown, sandy clay becoming coarser downwards.	
102 - 121 cms	Small gravel.	
121 - 134 cms	Grey clay.	
134 - 170 cms	Pink, silty sand.	
170 + cms	Gravel.	

BH 420	9.6 m O.D.	NS 8534 9634
0 - 51 cms	Red/brown sand.	
51 - 171 cms	Grey (carse) clay.	
171 - 180 cms	Pink, silty sand.	
180 + cms	Gravel.	

BH 421	9.9 m O.D.	NS 8532 9636
0 - 67 cms	Red/brown sand.	
67 - 166 cms	Grey (carse) clay.	
166 - 172 cms	Peat. Woody near base.	
172 - 177 cms	Grey, silty sand.	
177 - 179 cms	Pink sand.	
179 + cms	Gravel.	

BH 422	8.6 m O.D.	NS 8537 9625
0 - 73 cms	Red/brown, sandy clay.	
73 - 140 cms	Pink sand and small gravel with a considerable proportion of clay.	
140 - 169 cms	Coarse sand and small gravel. Wet and easily penetrated.	
169 - 178 cms	Sand and peat mixture.	
178 - 180 cms	Grey clay.	
180 - 219 cms	Exceedingly wet, brown sand.	
219 + cms	Gravel, possibly overlain by a thin band of grey clay.	

BH 423	8.3 m O.D.	NS 8539 9621
0 - 56 cms	Clay/sand mixture.	
56 + cms	Tough gravel.	

BH 424	8.4 m O.D.	NS 8538 9623
0 - 78 cms	Clay with a considerable proportion of sand.	
78 + cms	Pink sand and small gravel.	

BH 425	8.2 m O.D.	NS 8539 9617
0 - 149 cms	Clay/sand mixture.	
149 - 206 cms	Pink/grey, sandy silt with vegetable fragments in places.	
206 - 219 cms	Peat/clay mixture.	
219 - 230 cms	Coarse sand and gravel, grey in colour and very wet.	
230 - 260 cms	Grey sand with thin band of grey clay on top. Occasional stones.	
260 + cms	Pink, silty sand.	

BH 426	8.6 m O.D.	NS 8539 9612
0 - 160+ cms	Red/brown, sandy clay.	

BH 427	8.2 m O.D.	NS 8633 9368
0 - 194 cms	Carse-clay. Band of shells at 120-125 cms mostly *Cardium*. Quite sandy from 150 cms with *Ostrea* and *Mytilus* fragments.	
194 - 247 cms	Peat. Woody near base.	
247 - 297 cms	Grey/green, silty clay.	
297 - 411 cms	Grey, silty sand.	
411 + cms	Gravel.	
BH 428	8.1 m O.D.	NS 8632 9365
0 - 202 cms	Carse. Very sandy and rich in shell fragments *(Ostrea)* between 190 and 200 cms.	
202 - 251 cms	Peat. Woody in places.	
251 - 298 cms	Grey/green, silty clay.	
298 + cms	Grey, silty sand.	
BH 429	8.2 m O.D.	NS 8631 9359
0 - 224 cms	Carse. Sandy in places.	
224 - 282 cms	Peat. Very woody near base.	
282 - 327 cms	Grey, silty clay.	
327 + cms	Grey, silty sand.	
BH 430	7.5 m O.D.	NS 8628 9351
0 - 219 cms	Carse.	
219 - 254 cms	Peat. Tree at top.	
254 - 347 cms	Grey, silty clay.	
347 + cms	Grey, silty sand.	
BH 431	6.9 m O.D.	NS 8623 9344
0 - 306 cms	Carse. Quite tough at top.	
306 + cms	Grey, silty sand.	
BH 432	7.2 m O.D.	NS 8626 9347
0 - 240 cms	Carse.	
240 - 252 cms	Shelly sand.	
252 - 255 cms	Grey clay.	
255 - 256 cms	Peat.	
256 - 333 cms	Grey clay.	
333 + cms	Grey, silty sand.	
BH 433	7.2 m O.D.	NS 8627 9349
0 - 232 cms	Carse. Quite sandy in places and shelly in bottom 10-15 cms.	
232 - 253 cms	Peat.	
253 - 304 cms	Grey/green, silty clay.	
304 + cms	Grey, silty sand.	
BH 434	6.2 m O.D.	NS 8621 9341
0 - 250+ cms	Carse. Includes shelly sand *(Ostrea)* 250-260 cms. Becomes sandier downwards merging with the grey sand somewhere about 250-300 cms.	
BH 435	6.7 m O.D.	NS 8622 9343
0 - 283 cms	Carse. Becomes very sandy downwards.	
283 + cms	Grey, silty sand. Very rich in mica.	

BH 436 — 6.7 m O.D. — NS 8619 9332

0 - 465+ cms	Carse. Becomes tougher and darker downwards, penetration not being possible beyond 465 cms where carse-clay is blue/grey with shells.

BH 437 — 3.1 m O.D. — NS 8617 9326

0 - 98 cms	Grey/brown clay with abundant vegetable remains.
98 - 105 cms	Red/brown, coarse sand.
105 - 116 cms	Grey, coarse sand.
116 + cms	Intermixed layers of dark blue/black clay and sand. Some shells *(Mytilus)*.

BH 438 — 3.0 m O.D. — NS 8613 9319

0 - 107 cms	Grey/brown clay.
107 - 422 cms	Dark blue/black clay. Includes layers of grey sand and becomes coarser and tougher downwards.
422 + cms	Gravel.

BH 439 — 8.2 m O.D. — NS 8637 9389

0 - 191 cms	Carse.
191 - 259 cms	Peat. Woody in places.
259 - 350 cms	Grey clay.
350 + cms	Pink, silty sand and small gravel.

BH 440 — 7.9 m O.D. — NS 8635 9385

0 - 178 cms	Carse.
178 - 242 cms	Peat.
242 - 302 cms	Grey/green, silty clay.
302 - 372 cms	Grey, silty sand.
372 + cms	Rock or big gravel.

BH 441 — 7.9 m O.D. — NS 8634 9378

0 - 184 cms	Carse. Shell fragments at 80-90 cms. Mainly *Cardium* but with *Mytilus*.
184 - 237 cms	Peat mixed somewhat with clay in top few cms.
237 - 323 cms	Grey/green, silty clay.
323 - 379 cms	Grey, silty sand.
379 + cms	Gravel.

BH 442 — 7.0 m O.D. — NS 8593 9401

0 - 175 cms	Carse.
175 - 206 cms	Peat. Woody at top.
206 - 244 cms	Grey, silty clay.
244 + cms	Grey, silty sand.

BH 443 — 8.1 m O.D. — NS 8629 9394

0 - 151 cms	Carse.
151 - 162 cms	Transition zone.
162 - 230 cms	Woody peat.
230 - 314 cms	Grey clay.
314 + cms	Pink sand and small gravel.

BH 444	7.9 m O.D.	NS 8628 9392
0 - 137 cms	Carse.	
137 - 154 cms	Transition zone.	
154 - 216 cms	Peat.	
216 - 314 cms	Grey clay.	
314 + cms	Pink, silty sand and small gravel.	
BH 445	7.6 m O.D.	NS 8627 9391
0 - 138 cms	Carse.	
138 - 151 cms	Transition zone.	
151 - 198 cms	Peat.	
198 - 267 cms	Grey clay.	
267 - 294 cms	Grey, silty sand. Very tough.	
294 + cms	Pink, silty sand and small gravel.	
BH 446	8.1 m O.D.	NS 8630 9398
0 - 135 cms	Carse.	
135 - 152 cms	Transition zone.	
152 - 221 cms	Peat.	
221 - 294 cms	Grey clay. Coarser with depth.	
294 + cms	Big gravel and grey sand.	
BH 447	7.8 m O.D.	NS 8621 9397
0 - 138 cms	Carse.	
138 - 147 cms	Transition zone.	
147 - 205 cms	Peat.	
205 - 291 cms	Grey clay.	
291 + cms	Gravel.	
BH 448	7.7 m O.D.	NS 8619 9395
0 - 126 cms	Carse.	
126 - 152 cms	Transition zone.	
152 - 213 cms	Peat.	
213 - 262 cms	Grey (silty) clay.	
262 - 340 cms	Grey, silty sand. Slightly pink near base.	
340 + cms	Tough, plastic, pink, silty sand and small gravel.	
BH 449	7.0 m O.D.	NS 8618 9391
0 - 223 cms	Carse.	
223 + cms	Rock or big gravel.	
BH 450	7.4 m O.D.	NS 8607 9396
0 - 266 cms	Carse.	
266 + cms	Rock or big gravel(?).	
BH 451	7.7 m O.D.	NS 8608 9398
0 - 323 cms	Carse.	
323 + cms	Sand and gravel overlain by relatively thin layer of grey, silty sand.	

BH 452		8.2 m O.D.	NS 8609 9401
0 - 173 cms	Carse.		
173 - 209 cms	Clay/peat mixture (including reed heads).		
209 - 264 cms	Peat.		
264 - 328 cms	Grey clay.		
328 - 346 cms	Grey, silty sand and some small gravel near base.		
346 + cms	Coarse, pink, silty sand and small gravel.		
BH 453		8.4 m O.D.	NS 8611 9403
0 - 170 cms	Carse.		
170 - 205 cms	Transition zone.		
205 - 269 cms	Peat.		
269 - 313 cms	Grey clay.		
313 - 319 cms	Grey, silty sand.		
319 + cms	Coarse, pink, silty sand and small gravel.		
BH 454		8.3 m O.D.	NS 8596 9409
0 - 70 cms	Carse.		
70 + cms	Boring stopped by broken rock fragments (Rockhead? or Fill?).		
BH 455		7.9 m O.D.	NS 8595 9408
0 - 170 cms	Carse.		
170 - 199 cms	Transition zone.		
199 - 251 cms	Peat. Mixed with lenses of clay near base.		
251 - 261 cms	Grey, silty clay.		
261 - 279 cms	Grey, silty sand.		
279 + cms	Pink, silty sand and small gravel.		
BH 456		7.3 m O.D.	NS 8594 9404
0 - 151 cms	Carse.		
151 - 160 cms	Transition zone.		
160 - 191 cms	Peat.		
191 - 232 cms	Grey, silty clay.		
232 - 258 cms	Tough, grey, silty sand.		
258 + cms	Tough, pink, silty sand.		
BH 457		8.5 m O.D.	NS 8641 9388
0 - 225 cms	Carse.		
225 - 294 cms	Peat.		
294 - 377 cms	Grey clay. Slightly sandier near base.		
377 + cms	Coarse, pink sand and small gravel.		
BH 458		8.6 m O.D.	NS 8672 9381
0 - 88 cms	Carse.		
88 - 178 cms	Peat.		
178 + cms	Grey/brown sand.		
BH 459		8.7 m O.D.	NS 8666 9383
0 - 89 cms	Carse.		
89 - 121 cms	Coarse sand and gravel. Loosely packed.		
121 - 176 cms	Peat.		
176 - 320 cms	Grey clay/sand mixed considerably with peat in top 5-6 cms.		
320 + cms	Coarse sand and gravel.		

BH 460		9.1 m O.D.	NS 8662 9381
0 - 133	cms	Carse.	
133 - 156	cms	Coarse sand and sandstone gravel. Loosely packed.	
156 - 286	cms	Grey clay (carse?).	
286 - 363	cms	Peat.	
363 - 460	cms	Grey clay.	
460 +	cms	Coarse, pink, silty sand and small gravel.	

BH 461		8.8 m O.D.	NS 8661 9377
0 - 146	cms	Carse.	
146 - 166	cms	Coarse sand and gravel. Some shells near base.	
166 - 267	cms	Grey clay (carse?).	
267 - 328	cms	Peat.	
328 - 463	cms	Grey clay.	
463 +	cms	Grey/pink, tough, silty sand.	

BH 462		8.4 m O.D.	NS 8659 9368
0 - 155	cms	Carse.	
155 - 170	cms	Coarse sand and gravel with shells.	
170 - 251	cms	Grey clay (carse?).	
251 - 259	cms	Transition zone.	
259 - 315	cms	Peat.	
315 - 458	cms	Grey clay.	
458 +	cms	Grey, slightly pink, silty sand.	

BH 463		9.3 m O.D.	NS 8664 9386
0 - 123	cms	Carse. Sandy with depth.	
123 - 159	cms	Coarse sand and gravel.	
159 - 228	cms	Grey clay (carse?).	
228 - 382	cms	Peat. Quite woody.	
382 - 453	cms	Grey clay. Slightly pink near base.	
453 +	cms	Rock or big gravel.	

BH 464		10.0 m O.D.	NS 8658 9387
0 - 175	cms	Carse. Increasing sandy beyond 100 cms.	
175 +	cms	Coarse sand and gravel. Tightly packed.	

BH 465		9.7 m O.D.	NS 8656 9386
0 - 232	cms	Carse.	
232 - 383	cms	Peat.	
383 - 497	cms	Grey clay.	
497 +	cms	Pink, silty sand and small gravel.	

BH 466		8.9 m O.D.	NS 8650 9388
0 - 245	cms	Carse.	
245 - 344	cms	Very woody peat.	
344 - 427	cms	Grey clay. Coarser near base.	
427 +	cms	Pink, silty sand and small gravel.	

BH 467		8.5 m O.D.	NS 8645 9389
0 - 210	cms	Carse.	
210 - 223	cms	Transition zone.	
223 - 301	cms	Peat.	
301 - 376	cms	Grey clay. Tougher near base.	
376 +	cms	Coarse, pink sand and small gravel.	

BH 468		9.7 m O.D.	NS 9123 9112
0 - 150	cms	Carse. Very sandy, with stones near base.	
150 +	cms	Rock.	
BH 469		9.4 m O.D.	NS 9123 9111
0 - 172	cms	Carse. Very sandy and stoney.	
172 +	cms	Rock (Sandstone?).	
BH 470		8.4 m O.D.	NS 9123 9108
0 - 100	cms	Carse.	
100 - 133	cms	Coarse, yellow/brown sand.	
133 - 202	cms	Carse-clay. Quite sandy.	
202 +	cms	Coal(?). Quite soft in top few centimetres.	
BH 471		7.5 m O.D.	NS 9122 9104
0 - 101	cms	Carse, with sand layers and stones.	
101 +	cms	Rock (Sandstone?).	
BH 472		7.8 m O.D.	NS 9135 9105
0 - 173	cms	Carse. Very sandy and stoney near base.	
173 +	cms	Rock (Sandstone?).	
BH 473		7.2 m O.D.	NS 9122 9099
0 - 102	cms	Carse.	
102 +	cms	Rock.	
BH 474		7.1 m O.D.	NS 9123 9009
0 - 118	cms	Carse. Shell fragments at base.	
118 +	cms	Rock.	
BH 475		6.5 m O.D.	NS 9121 9092
0 - 256	cms	Carse. Slightly coarser with depth.	
256 +	cms	Rock.	
BH 476		5.9 m O.D.	NS 9119 9083
0 - 289	cms	Carse. Some shells near base.	
289 +	cms	Rock.	
BH 477		6.2 m O.D.	NS 9117 9074
0 - 358	cms	Carse. Tough, very shelly near base.	
358 +	cms	Rock.	
BH 478		5.5 m O.D.	NS 9115 9063
0 - 368	cms	Carse.	
368 +	cms	Tough, chocolate brown sand.	
BH 479		5.8 m O.D.	NS 9116 9069
0 - 384	cms	Carse.	
384 +	cms	Very tough, grey/brown sand.	
BH 480		6.1 m O.D.	NS 9117 9072
0 - 401	cms	Carse. Shells near base.	
401 +	cms	Rock.	

BH 481		5.5 m O.D.	NS 9115 9059
0 - 347 cms	Carse. Shells near base.		
347 + cms	Rock.		
BH 482		5.8 m O.D.	NS 9116 9063
0 - 416 cms	Carse. Quite tough with shells near base.		
416 + cms	Chocolate brown sand.		
BH 483		5.6 m O.D.	NS 9113 9051
0 - 422 cms	Carse. Very sandy near base with numerous shells.		
422 + cms	Broken or rotted rock.		
BH 484		5.5 m O.D.	NS 9112 9043
0 - 446 cms	Carse. Quite tough. Very black and shelly near base.		
446 + cms	Rock.		
BH 485		5.4 m O.D.	NS 9109 9035
0 - 410 cms	Carse. Very tough with thick shell bed in lower 50 cms.		
410 + cms	Rock.		
BH 486		4.4 m O.D.	NS 9108 9017
0 - 549 cms	Carse.		
549 + cms	Coarse, grey sand and shell fragments.		
BH 487		4.5 m O.D.	NS 9108 9008
0 - 550+ cms	Very tough carse.		
BH 488		4.2 m O.D.	NS 9108 9029
0 - 402 cms	Carse. Shelly and sandy near base.		
402 + cms	Broken rock and coarse, grey sand.		
BH 489		10.9 m O.D.	NS 8273 9604
0 - 337 cms	Carse.		
337 - 353 cms	Peat.		
353 - 361 cms	Soft, grey clay.		
361 + cms	Tough, grey/green, silty sand.		
BH 490		11.6 m O.D.	NS 8269 9604
0 - 407 cms	Carse.		
407 - 418 cms	Peat.		
418 - 451 cms	Tough, grey/green, silty sand.		
451 + cms	Pink, silty sand.		
BH 491		11.6 m O.D.	NS 8267 9608
0 - 394 cms	Very tough carse.		
394 - 403 cms	Peat.		
403 + cms	Grey/green, silty sand. Boring stopped at 454 cms by toughness of deposit. Pink clay may have been present in end of borer.		

BH 492		11.6 m O.D.	NS 8263 9612
0 - 396	cms	Extremely tough carse.	
396 - 407	cms	Peat.	
407 - 439	cms	Grey/green, silty sand.	
439 +	cms	Pink, silty sand.	
BH 493		10.6 m O.D.	NS 8259 9615
0 - 356	cms	Tough carse. Quite soft near base.	
356 - 381	cms	Dark grey sand.	
381 +	cms	Pink sand with small stones.	
BH 494		9.9 m O.D.	NS 8253 9609
0 - 329	cms	Carse.	
329 - 352	cms	Light grey, silty sand.	
352 +	cms	Grey, silty sand with stones.	
BH 495		10.3 m O.D.	NS 8254 9607
0 - 466	cms	Carse.	
466 +	cms	Coarse, pink/grey sand and gravel.	
BH 496		10.5 m O.D.	NS 8255 9605
0 - 461	cms	Carse.	
461 +	cms	Coarse, pink sand.	
BH 497		10.4 m O.D.	NS 8253 9604
0 - 294	cms	Carse.	
294 - 299	cms	Peat.	
299 - 328	cms	Grey/green, micaceous, silty sand.	
328 +	cms	Pink, silty sand.	
BH 498		10.3 m O.D.	NS 8249 9603
0 - 298	cms	Carse.	
298 +	cms	Grey/green, silty sand.	
BH 499		9.3 m O.D.	NS 8245 9602
0 - 357	cms	Carse.	
357 +	cms	Coarse, pink sand and small gravel.	
BH 500		9.7 m O.D.	NS 8251 9606
0 - 251	cms	Carse.	
251 +	cms	Tough, brown/grey sand.	
BH 501		9.9 m O.D.	NS 8246 9598
0 - 261	cms	Carse.	
261 - 264	cms	Peat (mixed with clay).	
264 - 289	cms	Grey/green, silty sand.	
289 +	cms	Grey/pink, silty sand, with some coarse, pink sand.	
BH 502		9.2 m O.D.	NS 8239 9592
0 - 200	cms	Carse. Mixed with some peat near base.	
200 - 248	cms	Grey/green, silty sand.	
248 +	cms	Pink, silty sand.	

BH 503		9.0 m O.D.	NS 8243 9596
0 - 153 cms	Carse.		
153 + cms	Grey, silty sand. Dark near top, lighter downwards.		
BH 504		8.9 m O.D.	NS 8243 9594
0 - 169 cms	Carse.		
169 - 173 cms	Clay/peat mixture.		
173 + cms	Grey/green, silty sand.		
BH 505		9.4 m O.D.	NS 8245 9599
0 - 291 cms	Carse.		
291 + cms	Dark grey, silty sand.		
BH 506		10.4 m O.D.	NS 8251 9598
0 - 353+ cms	Very sandy carse.		
BH 507		10.2 m O.D.	NS 8253 9598
0 - 271 cms	Carse.		
271 - 279 cms	Transition zone.		
279 - 284 cms	Peat.		
284 - 319 cms	Grey/green, silty sand.		
319 + cms	Pink, silty sand.		
BH 508		10.4 m O.D.	NS 8257 9598
0 - 281 cms	Carse.		
281 - 290 cms	Peat.		
290 + cms	Grey/green, silty sand.		
BH 509		10.1 m O.D.	NS 8259 9598
0 - 456 cms	Carse.		
456 + cms	Coarse, pink sand.		
BH 510		10.0 m O.D.	NS 8259 9589
0 - 562 cms	Carse. Shells from 500 cms to base.		
562 + cms	Pink sand and some gravel.		
BH 511		10.0 m O.D.	NS 8256 9589
0 - 335 cms	Carse.		
335 - 346 cms	Peat (mixed with clay on top and silty sand on bottom).		
346 + cms	Grey/green, silty sand.		
BH 512		9.5 m O.D.	NS 8258 9581
0 - 337 cms	Carse.		
337 - 355 cms	Peat.		
355 + cms	Grey/green, silty sand.		
BH 513		9.4 m O.D.	NS 8258 9572
0 - 356 cms	Carse.		
356 - 363 cms	Peat.		
363 + cms	Grey/green, clayey sand.		

BH 514		9.3 m O.D.	NS 8258 9567
0 - 347 cms	Carse.		
347 - 353 cms	Peat.		
353 + cms	Grey/green, silty sand.		
BH 515		9.4 m O.D.	NS 8258 9565
0 - 356 cms	Carse.		
356 - 373 cms	Peat.		
373 + cms	Grey/green, silty sand with some clay.		
BH 516		8.4 m O.D.	NS 8258 9562
0 - c310 cms	Carse.		
310 - 366 cms	Grey, silty sand and clay.		
366 + cms	Grey/brown to pink, silty sand.		
BH 517		9.5 m O.D.	NS 8252 9563
0 - 477+ cms	Carse. Increasingly sandy with depth.		
BH 518		9.4 m O.D.	NS 8248 9563
0 - 534 cms	Carse. Increasingly tough and sandy with depth.		
534 + cms	Coarse sand and gravel (Sandstone and coal fragments).		
BH 519		9.2 m O.D.	NS 8249 9554
0 - 400+ cms	Carse. Tough and sandy with depth.		
BH 520		9.3 m O.D.	NS 8248 9565
0 - 550 cms	Very coarse carse.		
550 + cms	Small gravel.		
BH 521		9.5 m O.D.	NS 8251 9568
0 - 481+ cms	Carse. Increasingly tough and sandy with depth.		
BH 522		Not Levelled	NS 8311 9597
0 - 378 cms	Carse.		
378 - 393 cms	Very tough clay/peat mixture.		
393 - 407 cms	Peat.		
407 - 430 cms	Grey/green, silty sand.		
430 + cms	Very tough, pink, silty sand.		
BH 523		Not Levelled	NS 8314 9591
0 - 331 cms	Carse.		
331 - 338 cms	Clay/peat mixture.		
338 - 353 cms	Peat.		
353 + cms	Grey/green, silty sand.		
BH 524		12.0 m O.D.	NS 8158 9617
0 - 70 cms	Carse.		
70 - 133 cms	Soft peat.		
133 + cms	Coarse, brown sand and gravel.		
BH 525		12.2 m O.D.	NS 8157 9617
0 - 65 cms	Carse.		
65 - 92 cms	Peat.		
92 + cms	Coarse sand and gravel.		

BH 526		11.9 m O.D.	NS 8159 9616
0 - 75 cms	Carse.		
75 - 169 cms	Soft peat.		
169 + cms	Coarse, brown sand and gravel.		
BH 527		12.0 m O.D.	NS 8162 9616
0 - 121 cms	Carse.		
121 - 213 cms	Soft, woody peat.		
213 - 271 cms	Brown/pink, silty sand.		
271 + cms	Coarse sand and gravel.		
BH 528		11.9 m O.D.	NS 8161 9616
0 - 96 cms	Carse.		
96 - 201 cms	Peat.		
201 - 254 cms	Pink, silty sand.		
254 + cms	Gravel.		
BH 529		12.0 m O.D.	NS 8164 9615
0 - 168 cms	Carse.		
168 - 258 cms	Peat.		
258 - 288 cms	Pink, silty sand.		
288 + cms	Coarse, pink sand and small gravel.		
BH 530		12.5 m O.D.	NS 8156 9608
0 - 123 cms	Carse.		
123 - 165 cms	Peat.		
165 + cms	Coarse, brown sand and small gravel.		
BH 531		12.2 m O.D.	NS 8157 9608
0 - 126 cms	Carse.		
126 - 197 cms	Peat.		
197 + cms	Coarse, brown sand on rock or big gravel.		
BH 532		12.2 m O.D.	NS 8158 9608
0 - 186 cms	Carse.		
186 - 235 cms	Peat.		
235 + cms	Rock or very big gravel.		
BH 533		12.2 m O.D.	NS 8159 9607
0 - 187 cms	Carse.		
187 - 257 cms	Peat.		
257 + cms	Coarse sand and gravel.		
BH 534		12.1 m O.D.	NS 8161 9607
0 - 216 cms	Carse.		
216 - 281 cms	Peat.		
281 + cms	Rock or big gravel.		
BH 535		11.8 m O.D.	NS 8164 9606
0 - 194 cms	Carse.		
194 - 268 cms	Peat. Mixed with clay in top 10-15 cms.		
268 + cms	Very coarse, pink, silty sand.		

BH 536		12.4 m O.D.	NS 8154 9601
0 - 159 cms	Carse.		
159 - 191 cms	Peat. Mixed with clay in top 10 cms.		
191 + cms	Coarse, brown sand.		
BH 537		12.0 m O.D.	NS 8155 9601
0 - 192 cms	Carse.		
192 - 201 cms	Peat.		
201 + cms	Tough, brown sand.		
BH 538		11.9 m O.D.	NS 8158 9599
0 - 222 cms	Carse.		
222 - 230 cms	Peat.		
230 - 241 cms	Grey/green, silty clay.		
241 + cms	Coarse, pink, silty sand.		
BH 539		12.0 m O.D.	NS 8159 9599
0 - 216 cms	Carse.		
216 - 225 cms	Peat.		
225 + cms	Coarse, grey sand.		
BH 540		12.1 m O.D.	NS 8159 9603
0 - 235 cms	Carse.		
235 - 256 cms	Peat.		
256 + cms	Coarse, grey sand.		
BH 541		12.1 m O.D.	NS 8158 9602
0 - 249 cms	Carse.		
249 - 266 cms	Peat.		
266 + cms	Grey/brown sand.		
BH 542		7.6 m O.D.	NS 8463 9518
0 - 290+ cms	Tough, red/brown sand.		
BH 543		7.2 m O.D.	NS 8461 9518
0 - 224 cms	Carse. Tough and very sandy in top 30-40 cms. Softer near base.		
224 + cms	Gravel.		
BH 544		6.6 m O.D.	NS 8457 9519
0 - 167 cms	Carse.		
167 + cms	Coarse, grey sand and small gravel.		
BH 545		7.2 m O.D.	NS 8454 9519
0 - 244 cms	Carse.		
244 + cms	Coarse, grey/pink sand and small gravel.		
BH 546		8.0 m O.D.	NS 8449 9519
0 - 286 cms	Carse.		
286 + cms	Rock or big gravel with thin layer of pink/grey sand on top.		

BH 547	8.0 m O.D.	NS 8445 9519
0 - 311 cms	Carse. Very dark and sandy near base.	
311 + cms	Black sand and small gravel.	
BH 548	6.8 m O.D.	NS 8459 9519
0 - 100+ cms	Orange/red sand.	
BH 549	7.8 m O.D.	NS 8441 9519
0 - 362 cms	Carse. Dark and sandy near base.	
362 + cms	Coarse sand and gravel.	
BH 550	8.3 m O.D.	NS 8428 9518
0 - ? cms	Carse.	
? - 243 cms	Peat.	
243 - 280 cms	Grey, silty clay.	
280 + cms	Quite coarse, grey, silty sand.	
BH 551	8.0 m O.D.	NS 8432 9518
0 - 194 cms	Carse.	
194 - 215 cms	Peat.	
215 - 244 cms	Grey, silty clay.	
244 + cms	Grey, silty sand.	
BH 552	7.7 m O.D.	NS 8435 9518
0 - 299 cms	Carse. Very black with some shells near base.	
299 + cms	Pink/grey, silty sand.	
BH 553	7.7 m O.D.	NS 8419 9518
0 - 164 cms	Carse.	
164 - 180 cms	Coarse, brown sand.	
180 - 325 cms	Carse-clay with sandy bands. Very dark near base.	
325 + cms	Light grey, silty sand.	
BH 554	8.0 m O.D.	NS 8422 9518
0 - 220 cms	Carse.	
220 - 223 cms	Peat.	
223 - 246 cms	Grey, silty sand.	
246 + cms	Grey/pink, silty sand.	
BH 555	8.8 m O.D.	NS 8422 9527
0 - 440+ cms	Carse. Contains bands of sand that increase in frequency with depth.	
BH 556	8.8 m O.D.	NS 8431 9527
0 - 217 cms	Carse.	
217 - 241 cms	Peat.	
241 + cms	Grey/green, silty clay.	
BH 557	7.2 m O.D.	NS 8404 9515
0 - 450 cms	Carse. Tough and sandy with depth.	
450 + cms	Coarse sand and gravel.	
BH 558	Not Levelled	NS 8403 9539
0 - 462+ cms	Carse with sand and shell beds from c.320 cms.	

BH 559		8.5 m O.D.	NS 8439 9527
0 - 348 cms	Carse. Coarser with depth.		
348 + cms	Coarse sand and gravel.		
BH 560		8.4 m O.D.	NS 8435 9527
0 - 336+ cms	Carse. Increasingly tough with depth.		
BH 561		8.4 m O.D.	NS 8439 9535
0 - 325+ cms	Carse. Dark, sandy and tough.		
BH 562		8.8 m O.D.	NS 8431 9535
0 - 300+ cms	Carse. Darker and sandier with depth.		
BH 563		7.1 m O.D.	NS 8445 9535
0 - 95 cms	Red/brown sand.		
95 + cms	Coarse sand and gravel.		
BH 564		8.2 m O.D.	NS 8443 9535
0 - 248 cms	Carse. Coarser with depth.		
248 + cms	Dark grey/black, coarse sand and small gravel.		
BH 565		6.6 m O.D.	NS 8445 9541
0 - 102 cms	Carse.		
102 + cms	Very coarse sand.		
BH 566		Not Levelled	NS 8443 9552
0 - 207 cms	Very tough carse.		
207 + cms	Gravel and coarse sand.		
BH 567		Not Levelled	NS 8439 9551
0 - 233+ cms	Very coarse, red/brown sand.		
BH 568		Not Levelled	NS 8435 9551
0 - 200+ cms	Coarse but soft, red/brown sand.		
BH 569		11.2 m O.D.	NS 8424 9672
0 - 161 cms	Carse.		
161 - 175 cms	Clay/peat mixture.		
175 + cms	Pink, silty sand and clay.		
BH 570		11.3 m O.D.	NS 8425 9667
0 - 197 cms	Carse.		
197 + cms	Pink, silty sand. Some peat mixed in top 4-5 cms.		
BH 571		11.5 m O.D.	NS 8428 9657
0 - 324 cms	Very tough carse.		
324 - 333 cms	Peat.		
333 + cms	Grey/pink, silty sand.		
BH 572		11.4 m O.D.	NS 8427 9661
0 - 361 cms	Carse.		
361 + cms	Pink/brown sand.		

BH 573		11.4 m O.D.	NS 8425 9665
0 - 267 cms	Carse.		
267 - 271 cms	Clay/peat mixture.		
271 - 284 cms	Grey clay.		
284 + cms	Pink, silty sand.		
BH 574		11.3 m O.D.	NS 8431 9648
0 - 363 cms	Very tough carse.		
363 + cms	Tough, pink, silty sand.		
BH 575		11.3 m O.D.	NS 8431 9646
0 - 357 cms	Very tough carse.		
357 + cms	Pink, silty sand with 2-3 cms of grey, silty sand on top.		
BH 576		11.4 m O.D.	NS 8429 9652
0 - 302 cms	Extremely tough carse.		
302 + cms	Grey/pink, silty sand with 2-3 cms of mixed clay and peat on top.		
BH 577		11.5 m O.D.	NS 8419 9639
0 - 398 cms	Very tough carse.		
398 - 414 cms	Peat.		
414 - 430 cms	Grey, silty clay.		
430 + cms	Pink, silty sand.		
BH 578		8.7 m O.D.	NS 8407 9634
0 - 99 cms	Soft carse.		
99 - 108 cms	Peat.		
108 - 126 cms	Grey, silty sand.		
126 + cms	Pink, silty sand.		
BH 579		8.6 m O.D.	NS 8409 9626
0 - 115 cms	Carse. Shells at base.		
115 - 131 cms	Grey, silty sand.		
131 + cms	Pink, silty sand.		
BH 580		8.8 m O.D.	NS 8414 9618
0 - 122 cms	Carse.		
122 - 144 cms	Peat.		
144 + cms	Grey, silty sand.		
BH 581		8.4 m O.D.	NS 8422 9608
0 - 131 cms	Carse.		
131 - 148 cms	Peat.		
148 + cms	Grey, silty sand.		
BH 582		12.2 m O.D.	NS 8214 9688
0 - 65 cms	Slightly clayey peat.		
65 - 119 cms	Carse-clay.		
119 - 136 cms	Peat.		
136 + cms	Gravel.		

BH 583 12.4 m O.D. NS 8215 9685

0 - 189	cms	Carse.
189 - 237	cms	Peat.
237 +	cms	Pink, silty sand. Slightly grey in top 2-3 cms.

BH 584 12.4 m O.D. NS 8214 9687

0 - 145	cms	Carse.
145 - 201	cms	Peat.
201 +	cms	Pink, silty sand.

BH 585 11.9 m O.D. NS 8222 9688

0 - ?	cms	Carse. Mixed with gravel from adjacent fan.
? - 121	cms	Peat.
121 +	cms	Pink, silty sand. Slightly grey in top few cms.

BH 586 11.6 m O.D. NS 8222 9685

0 - ?	cms	Carse. Mixed with peat in top 40 cms.
? - 146	cms	Peat.
146 +	cms	Pink, silty sand. Slightly grey at top.

BH 587 11.5 m O.D. NS 8232 9683

0 - 121	cms	Carse.
121 - 152	cms	Peat. Mixed with clay in top 10 cms.
152 +	cms	Coarse, grey/brown sand.

BH 588 12.1 m O.D. NS 8232 9685

0 - 40	cms	Carse/gravel mixture.
40 +	cms	Gravel.

BH 589 11.6 m O.D. NS 8232 9684

0 - 71	cms	Carse.
71 +	cms	Gravel.

BH 590 11.3 m O.D. NS 8232 9682

0 - 154	cms	Carse.
154 - 189	cms	Peat.
189 +	cms	Coarse, pink/brown sand.

BH 591 11.6 m O.D. NS 8237 9683

0 - ?	cms	Carse.
? - 187	cms	Peat.
187 +	cms	Grey/brown, coarse, silty sand, becoming pink with depth.

BH 592 11.3 m O.D. NS 8236 9684

0 - 117	cms	Carse.
117 - 154	cms	Peat.
154 - 172	cms	Grey/pink, silty sand.
172 +	cms	Pink, silty sand.

BH 593 12.4 m O.D. NS 8249 9683

0 - 256	cms	Carse.
256 - 275	cms	Peat.
275 - 302	cms	Grey, silty clay.
302 +	cms	Pink clay and sand.

BH 594	12.1 m O.D.	NS 8248 9682
0 - 184 cms	Carse.	
184 - 217 cms	Peat.	
217 + cms	Pink, silty sand. Grey in top few cms.	
BH 595	12.0 m O.D.	NS 8261 9686
0 - 120 cms	Carse.	
120 - 186 cms	Peat.	
186 + cms	Pink, silty sand.	
BH 596	12.6 m O.D.	NS 6701 9924
0 - 72 cms	Sandy carse.	
72 + cms	Coarse, pink sand.	
BH 597	12.8 m O.D.	NS 6702 9921
0 - 97+ cms	Very tough, pink carse. From c.70 cms it contains pink and white sand - possibly rotted sandstone.	
BH 598	12.8 m O.D.	NS 6699 9917
0 - 99+ cms	Very sandy carse. Too tough to penetrate beyond 99 cms.	
BH 599	12.4 m O.D.	NS 6697 9912
0 - 130 cms	Red/brown sand.	
130 + cms	Rock or big gravel.	
BH 600	12.9 m O.D.	NS 6709 9925
0 - 79 cms	Mixed sand and clay. Sand increases in proportion from 79 cms and too tough to penetrate beyond c.93 cms.	
BH 601	13.2 m O.D.	NS 6708 9921
0 - 115 cms	Red/brown sand.	
115 - 201 cms	Grey carse-clay.	
201 + cms	Pink, silty sand.	
BH 602	13.1 m O.D.	NS 6708 9923
0 - 141 cms	Red/brown sand.	
141 - 171 cms	Grey carse-clay.	
171 + cms	Pink, silty sand.	
BH 603	13.3 m O.D.	NS 6717 9925
0 - 101 cms	Red/brown sand with some small gravel. Too tough to penetrate beyond 101 cms.	
BH 604	13.6 m O.D.	NS 6717 9923
0 - 117 cms	Red/brown sand.	
117 - 218 cms	Carse-clay.	
218 + cms	Several cms of pink, silty sand resting upon rotted grey sandstone.	
BH 605	14.4 m O.D.	NS 6727 9925
0 - 126 cms	Red/brown sand.	
126 + cms	Grey/white, silty sand with small gravel.	

BH 606	13.8 m O.D.	NS 6725 9923
0 - 127 cms	Brown, clayey sand.	
127 - 211 cms	Blue/grey carse-clay.	
211 + cms	Very coarse, pink, silty sand.	
BH 607	13.7 m O.D.	NS 7627 9925
0 - 161 cms	Red/brown sand. More clayey with depth.	
161 + cms	Coarse, pink, silty sand.	
BH 608	13.5 m O.D.	NS 6726 9919
0 - 60 cms	Red/brown sand. Boring stopped at c.60 cms by solid sandstone or gravel.	
BH 609	13.7 m O.D.	NS 6727 9921
0 - 94 cms	Coarse, red/brown sand.	
94 + cms	Coarse gravel.	
BH 610	13.6 m O.D.	NS 6729 9919
0 - 92 cms	Red/brown sand. Some clay near base.	
92 + cms	Gravel.	
BH 611	13.6 m O.D.	NS 6727 9918
0 - 138 cms	Red/brown sand, giving way to coarse, brown/pink sand and gravel.	
BH 612	13.1 m O.D.	NS 6744 9874
0 - 256 cms	Carse with some sandy bands.	
256 + cms	Pink, silty sand.	
BH 613	13.0 m O.D.	NS 6754 9871
0 - 259 cms	Carse.	
259 + cms	Pink, silty sand.	
BH 614	13.6 m O.D.	NS 6756 9875
0 - 98 cms	Carse, with some sand.	
98 + cms	Coarse, grey/brown sand.	
BH 615	13.3 m O.D.	NS 6755 9873
0 - 253 cms	Carse.	
253 + cms	Pink, silty sand.	
BH 616	13.4 m O.D.	NS 6754 9874
0 - 219 cms	Carse.	
219 + cms	Coarse, pink sand and small gravel.	
BH 617	13.1 m O.D.	NS 6749 9864
0 - 367 cms	Carse.	
367 + cms	Pink, silty sand.	
BH 618	13.2 m O.D.	NS 6751 9868
0 - 311 cms	Carse.	
311 + cms	Pink, silty sand.	
BH 619	13.4 m O.D.	NS 6749 9869
0 - 335 cms	Carse.	
335 + cms	Pink, silty sand.	

BH 620	13.0 m O.D.	NS 6744 9856
0 - 448 cms	Carse.	
448 + cms	Coarse, pink sand.	
BH 621	13.2 m O.D.	NS 6742 9857
0 - 489 cms	Carse.	
489 + cms	Red sand. Includes some shell fragments.	
BH 622	12.9 m O.D.	NS 6741 9849
0 - 501 cms	Carse. Shelly near base.	
501 - 507 cms	Red, shelly sand.	
507 + cms	Light grey, tough sand.	
BH 623	12.9 m O.D.	NS 6738 9845
0 - 382 cms	Carse.	
382 + cms	Tough, grey, silty sand.	
BH 624	12.8 m O.D.	NS 6742 9857
0 - 487 cms	Carse. Mixed with red, shelly sand near base.	
487 + cms	Grey, silty sand.	
BH 625	12.7 m O.D.	NS 6735 9875
0 - 107 cms	Carse.	
107 + cms	Pink, silty sand with some coarse, pink sand in top few cms.	
BH 626	11.8 m O.D.	NS 6722 9893
0 - 138 cms	Carse.	
138 + cms	Coarse, pink, silty sand and small gravel.	
BH 627	12.6 m O.D.	NS 6719 9893
0 - 371 cms	Carse.	
371 + cms	Pink, silty sand.	
BH 628	13.4 m O.D.	NS 6714 9879
0 - 462 cms	Carse. Quite sandy at top.	
462 + cms	Grey, silty sand.	
BH 629	13.6 m O.D.	NS 6718 9876
0 - 424 cms	Carse.	
424 + cms	Pink, silty sand.	
BH 630	16.1 m O.D.	NS 6284 9844
0 - 253 cms	Peat.	
253 - 872+ cms	Carse. Clay at top, but giving way to sandy clay and sand with depth.	
BH 631	13.2 m O.D.	NS 6279 9841
0 - 329 cms	Peat.	
329 + cms	Carse-clay.	

Boring stopped at 776 cms where grey, silty sand was present. Exact details of stratigraphy not known, but top of buried peat thought to be at c.400-420 cms.

BH 632	16.3 m O.D.	NS 6292 9848
0 - 210 cms	Peat.	
210 - 629 cms	Carse-clay.	
629 - 654 cms	Peat.	
654 + cms	Grey, silty sand.	

BH 633	13.5 m O.D.	NS 6289 9847
0 - 65 cms	Peat.	
65 - 626 cms	Carse-clay. Coarser with depth.	
626 + cms	Coarse, grey/brown sand, too tough for further boring.	

BH 634	14.1 m O.D.	NS 6372 0048
0 - 112 cms	Red sand, with some clay.	
112 - 125 cms	Peat.	
125 + cms	Pink, silty sand, grading to sand at c.140 cms.	

BH 635	14.0 m O.D.	NS 6371 0047
0 - ? cms	Carse.	
? - 116 cms	Peat.	
116 + cms	Pink, silty sand, grading to pink sand.	

BH 636	13.5 m O.D.	NS 6368 0044
0 - 85 cms	Carse.	
85 - 87 cms	Peat.	
87 - 111 cms	Pink, silty sand, grading to pink sand.	
111 + cms	Coarse, red sand and gravel.	

BH 637	13.8 m O.D.	NS 6368 0041
0 - 157 cms	Carse.	
157 - 168 cms	Peat.	
168 - 187 cms	Grey, silty clay.	
187 + cms	Pink sand.	

BH 638	13.5 m O.D.	NS 6372 0039
0 - 85 cms	Carse.	
85 - 97 cms	Clay/peat mixture.	
97 - 108 cms	Grey/pink, silty sand.	
108 + cms	Coarse, red sand.	

BH 639	14.1 m O.D.	NS 6436 0014
0 - 81 cms	Carse.	
81 - 87 cms	Peat.	
87 + cms	Grey/brown sand.	

BH 640	13.9 m O.D.	NS 6436 0013
0 - ? cms	Carse.	
? - 131 cms	Peat.	
131 - 140 cms	Grey, silty sand.	
140 + cms	Pink, silty sand.	

BH 641	13.7 m O.D.	NS 6436 0008
0 - 183 cms	Carse.	
183 + cms	Pink, silty sand.	

BH 642	13.8 m O.D.	NS 6436 0011
0 - 117 cms	Carse.	
117 - 135 cms	Peat.	
135 - 141 cms	Grey clay and sand.	
141 + cms	Pink, silty sand.	

BH 643	13.0 m O.D.	NS 6438 9999
0 - 165 cms	Carse. Coarser with depth.	
165 - 211 cms	Coarse (but soft) grey/brown sand.	
211 + cms	Coarse, grey sand including some clay but very tough.	

BH 644	12.2 m O.D.	NS 6439 9997
0 - 269 cms	Carse. Darker with depth.	
269 + cms	Fine, grey/brown sand.	

BH 645	13.6 m O.D.	NS 6432 9992
0 - 491 cms	Carse. Shells at c.350 cms.	
491 + cms	Rock (or big gravel).	

BH 646	13.8 m O.D.	NS 6433 9988
0 - 575 cms	Carse.	
575 + cms	Very coarse, black sand.	

BH 647	14.0 m O.D.	NS 6434 9984
0 - 550+ cms	Carse.	

Dark blue/black carse-clay still present at 550 cms.

BH 648	13.0 m O.D.	NS 6414 9994
0 - 447 cms	Carse.	
447 + cms	Rock (or big gravel).	

BH 649	13.7 m O.D.	NS 6415 9985
0 - 313 cms	Carse.	

313 - c.420 cms Peat, mixed with clay in top 5-6 cms. Peat still present at 358 cms where it is too tough to penetrate. Comparison with other holes suggests that grey, silty sand is probably present at c.420 cms.

c.420 + cms	Grey, silty sand.	

BH 650	13.6 m O.D.	NS 6415 9989
0 - 532 cms	Carse.	
532 + cms	Coarse sand and small gravel.	

BH 651	13.4 m O.D.	NS 6383 9989
0 - 235 cms	Carse.	
235 - 341 cms	Peat.	
341 + cms	Grey, silty sand.	

BH 652	13.5 m O.D.	NS 6388 9989
0 - 478 cms	Carse.	
478 + cms	Tough (but fine) grey sand.	

BH 653		11.6 m O.D.	NS 6381 9991
0 - 85 cms	Peat.		
85 - 284 cms	Grey, silty sand. Variable toughness. Extremely micaceous.		
284 + cms	Grey/pink sand.		
BH 654		13.8 m O.D.	NS 6375 9993
0 - 272 cms	Carse.		
272 + cms	Peat. Too tough to penetrate, but taken as indicative of grey, silty sand present at c.380-400 cms.		
BH 655		13.7 m O.D.	NS 6368 9997
0 - 285 cms	Carse.		
285 + cms	Peat.		
Grey, silty sand	present probably at 400+ cms.		
BH 656		Not Levelled	NS 6369 9998
0 - 223 cms	Carse.		
223 + cms	Peat. Too tough to penetrate.		
BH 657		14.9 m O.D.	NS 6273 0064
0 - 211 cms	Carse, mixed with peat in top 80 cms.		
211 + cms	Grey/brown, silty sand. Thin pink clay at junction.		
BH 658		14.6 m O.D.	NS 6274 0061
0 - 178 cms	Carse.		
178 + cms	Tough, brown, silty sand.		
BH 659		14.5 m O.D.	NS 6275 0057
0 - 174 cms	Carse.		
174 + cms	Brown, silty sand.		
BH 660		14.2 m O.D.	NS 6279 0049
0 - 251 cms	Carse.		
251 - 275 cms	Peat.		
275 + cms	Grey, silty sand.		
BH 661		14.4 m O.D.	NS 6277 0055
0 - 232 cms	Carse.		
232 + cms	Brown, silty sand.		
BH 662		14.5 m O.D.	NS 6276 0053
0 - 276 cms	Carse.		
276 + cms	Fine, brown sand.		
BH 663		14.4 m O.D.	NS 6278 0052
0 - 334 cms	Carse. Becoming blue/black with depth.		
334 + cms	Pink/brown, fine sand.		
BH 664		14.1 m O.D.	NS 6283 0042
0 - 310 cms	Carse.		
310 - 351 cms	Peat.		
351 + cms	Brown sand, mixed with peat.		

BH 665		14.2 m O.D.	NS 6285 0039
0 - 298 cms	Carse.		
298 - 346 cms	Peat.		
346 + cms	Grey, silty sand.		
BH 666		14.9 m O.D.	NS 6152 9944
0 - 183 cms	Peat.		
183 + cms	Gravel.		
BH 667		15.4 m O.D.	NS 6158 9952
0 - 643 cms	Peat and carse.		
643 - 651 cms	Peat.		
651 - 721 cms	Grey, silty sand.		
721 + cms	Gravel.		
BH 668		15.8 m O.D.	NS 6161 9959
0 - 800 cms	Peat and carse.		
800 + cms	Carse still present but penetration difficult.		
BH 669		14.0 m O.D.	NS 6167 9965
0 - 713 cms	Peat and carse.		
713 + cms	Carse still present but very tough.		
BH 670		14.3 m O.D.	NS 7166 9851
0 - ? cms	Carse mixed with peat.		
? - 327 cms	Peat.		
327 + cms	Coarse, grey/brown sand.		
BH 671		13.6 m O.D.	NS 7163 9848
0 - 217 cms	Carse.		
217 - 311 cms	Peat.		
311 + cms	Very tough, grey, silty sand.		
BH 672		13.9 m O.D.	NS 7165 9853
0 - 80 cms	Peat.		
80 - 321 cms	Carse.		
321 + cms	Grey, silty sand.		
BH 673		13.6 m O.D.	NS 7174 9854
0 - 45 cms	Peat.		
45 - ? cms	Carse.		
? - 299 cms	Peat.		
299 + cms	Grey, silty sand.		
BH 674		13.9 m O.D.	NS 7183 9855
0 - 288 cms	Carse. Mixed with peat at top.		
288 - 307 cms	Peat.		
307 + cms	Grey, silty sand.		
BH 675		14.5 m O.D.	NS 7192 9856
0 - 363 cms	Carse.		
363 - 375 cms	Peat.		
375 + cms	Grey, silty sand.		

BH 676		15.9 m O.D.	NS 7199 9858
0 - 100 cms	Sandy clay.		
100 - 196 cms	Clay.		
196 - 502 cms	Sandy clay.		
502 - 517 cms	Peat.		
517 + cms	Grey, silty sand.		
BH 677		13.2 m O.D.	NS 7237 9845
0 - 70 cms	Peat.		
70 - ? cms	Carse-clay.		
? - 353 cms	Peat.		
353 + cms	Tough, grey, silty sand.		
BH 678		13.2 m O.D.	NS 7245 9839
0 - 75 cms	Peat.		
75 - 343 cms	Carse.		
343 + cms	Grey/green, silty sand.		
BH 679		13.3 m O.D.	NS 7252 9835
0 - 60 cms	Peat.		
60 - 362 cms	Carse.		
362 + cms	Coarse sand and small gravel.		
BH 680		13.1 m O.D.	NS 7249 9837
0 - 45 cms	Peat.		
45 - 321 cms	Carse.		
321 - 326 cms	Peat.		
326 - 338 cms	Transition zone.		
338 - 361 cms	Grey, silty sand.		
361 + cms	Coarse, grey sand and small gravel.		
BH 681		11.9 m O.D.	NS 7271 9693
0 - 541 cms	Carse. Sandier with depth.		
541 - 563 cms	Sand with shell fragments.		
563 + cms	Medium and big gravel.		
BH 682		11.7 m O.D.	NS 7273 9701
0 - 486 cms	Very tough carse. Sandier with depth.		
486 - 518 cms	Sand and clay.		
518 + cms	Big gravel.		
BH 683		11.8 m O.D.	NS 7277 9709
0 - c.470 cms	Carse.		
470 - 509 cms	Very sandy clay with shells.		
509 + cms	Gravel.		
BH 684		11.7 m O.D.	NS 7281 9717
0 - 467 cms	Carse, increasingly sandy with depth.		
467 + cms	Medium to big gravel.		
BH 685		11.9 m O.D.	NS 7284 9728
0 - 429 cms	Carse.		
429 + cms	Tough, grey sand with shells on top.		

BH 686	11.9 m O.D.	NS 7285 9735
0 - 370 cms	Carse. Tough near base.	
370 - 408 cms	Grey, slightly green sand.	
408 + cms	Gravel.	
BH 687	11.8 m O.D.	NS 7278 9738
0 - 388 cms	Carse.	
388 - 409 cms	Grey, slightly green sand.	
409 + cms	Gravel.	
BH 688	11.8 m O.D.	NS 7274 9729
0 - 425 cms	Carse.	
425 - 437 cms	Coarse sand. Mainly grey but with green and pink streaks.	
437 + cms	Gravel.	
BH 689	11.5 m O.D.	NS 7047 9832
0 - 44 cms	Clay.	
44 - 92 cms	Peat.	
92 + cms	Grey/green, silty sand. Slightly pink with depth.	
BH 690	11.7 m O.D.	NS 7049 9829
0 - 57 cms	Clay.	
57 - 119 cms	Peat.	
119 + cms	Grey, silty sand.	
BH 691	11.9 m O.D.	NS 7065 9843
0 - 39 cms	Sandy carse.	
39 - 47 cms	Peat.	
47 + cms	Pink, sandy clay. Becoming gritty with depth.	
BH 692	11.3 m O.D.	NS 7067 9841
0 - 37 cms	Carse.	
37 - 53 cms	Peat.	
53 + cms	Very tough, grey, silty sand.	
BH 693	11.4 m O.D.	NS 7066 9842
0 - 42 cms	Carse.	
42 - 60 cms	Peat.	
60 - 93 cms	Grey, silty sand.	
93 + cms	Pink, silty sand.	
BH 694	12.9 m O.D.	NS 7083 9854
0 - 60 cms	Sandy carse.	
60 + cms	Tough sand.	
BH 695	12.1 m O.D.	NS 7085 9849
0 - 43 cms	Sandy carse.	
43 - 143 cms	Peat.	
143 - 166 cms	Grey, silty sand.	
166 + cms	Pink, silty sand.	

BH 696		11.9 m O.D.	NS 7084 9851
0 - 45 cms	Carse.		
45 - 97 cms	Peat.		
97 - 105 cms	Grey, silty sand.		
105 + cms	Pink, silty sand. Coarser with depth.		
BH 697		14.2 m O.D.	NS 7096 9869
0 - 63 cms	Sandy carse.		
63 - 88 cms	Clay.		
88 - 101 cms	Peat.		
101 + cms	Coarse, orange/brown sand.		
BH 698		14.3 m O.D.	NS 7027 9824
0 - 54 cms	Sandy clay.		
54 - 62 cms	Peat.		
62 - 112 cms	Clay.		
112 + cms	Red/brown sand.		
BH 699		13.8 m O.D.	NS 7029 9822
0 - 254 cms	Carse. Very sandy near base.		
254 - 335 cms	Peat.		
335 + cms	Grey/green, silty sand.		
BH 700		14.0 m O.D.	NS 7028 9823
0 - 177 cms	Carse.		
177 - 264 cms	Pink/grey sand.		
264 - 320 cms	Peat.		
320 + cms	Gritty, red sand.		
BH 701		12.9 m O.D.	NS 7021 9812
0 - 267 cms	Carse.		
267 - 348 cms	Woody peat.		
348 + cms	Grey, silty sand.		
BH 702		12.4 m O.D.	NS 6845 9795
0 - 489 cms	Carse.		
489 + cms	Tough, grey sand.		
BH 703		12.8 m O.D.	NS 6853 9769
0 - 344 cms	Carse.		
344 + cms	Tough, grey, shelly sand.		
BH 704		12.9 m O.D.	NS 6864 9802
0 - 169 cms	Carse.		
169 + cms	Gravel.		
BH 705		12.6 m O.D.	NS 7003 9804
0 - 338 cms	Carse.		
338 - 409 cms	Peat.		
409 + cms	Grey, silty sand. Coarser with depth.		
BH 706		13.5 m O.D.	NS 6987 9807
0 - 44 cms	Carse.		
44 + cms	Gravel.		

BH 707	13.5 m O.D.	NS 6987 9805
0 - 369 cms	Carse.	
369 - 462 cms	Peat. Tree at top.	
462 - 496 cms	Grey, silty sand. Slightly coarser with depth.	
496 + cms	Pink, silty sand.	
BH 708	14.4 m O.D.	NS 6641 9953
0 - 74 cms	Carse. Slightly peaty near base.	
74 + cms	Red/brown sand.	
BH 709	13.9 m O.D.	NS 6639 9947
0 - 42 cms	Carse.	
42 + cms	Coarse, red/brown sand.	
BH 710	13.8 m O.D.	NS 6639 9944
0 - 64 cms	Carse. Pinkish in colour.	
64 + cms	Tough, pink/purple sand.	
BH 711	13.5 m O.D.	NS 6638 9938
0 - 68 cms	Carse.	
68 - 73 cms	Coarse, pink/purple sand.	
73 + cms	Rock.	
BH 712	13.8 m O.D.	NS 6649 9934
0 - 92 cms	Carse.	
92 + cms	Pink/purple sand.	
BH 713	13.8 m O.D.	NS 6651 9939
0 - 63 cms	Carse.	
63 + cms	Coarse, red/brown or pink sand.	
BH 714	13.5 m O.D.	NS 6662 9934
0 - 72 cms	Carse.	
72 + cms	Coarse, red/pink sand.	
BH 715	13.7 m O.D.	NS 6662 9939
0 - 63 cms	Carse.	
63 + cms	Coarse, pink sand.	
BH 716	14.3 m O.D.	NS 6622 9958
0 - 79 cms	Peat and carse.	
79 + cms	Coarse, grey/brown sand.	
BH 717	13.9 m O.D.	NS 6623 9952
0 - 79 cms	Carse.	
79 + cms	Coarse, purple/pink sand.	
BH 718	14.6 m O.D.	NS 6613 9969
0 - 74 cms	Carse.	
74 + cms	Coarse, purple/pink sand.	
BH 719	14.0 m O.D.	NS 6614 9957
0 - 91 cms	Carse.	
91 + cms	Rock or gravel.	

BH 720		14.2 m O.D.	NS 6587 9959
0 - 242 cms	Carse.		
242 + cms	Pink, silty sand with some peat on top.		
BH 721		13.9 m O.D.	NS 6585 9954
0 - 364 cms	Carse. Very dark near base.		
364 + cms	Rock.		
BH 722		9.9 m O.D.	NS 7529 9689
0 - 588 cms	Carse. Sandy near base.		
588 + cms	Gravel and coarse, grey sand.		
BH 723		10.0 m O.D.	NS 7511 9675
0 - 564+ cms	Carse. Increasingly tough and sandy near base.		
BH 724		11.2 m O.D.	NS 7499 9665
0 - 668+ cms	Carse. Peaty on top. Very tough. Quite coarse and sandy near base.		
BH 725		9.8 m O.D.	NS 7497 9651
0 - 563+ cms	Carse. Peaty at top. Increasingly tough with depth.		
BH 726		10.5 m O.D.	NS 7513 9678
0 - 622+ cms	Carse. Very tough and sandy at base.		

* * * * * * *

Boreholes noted in the text with reference letters DES are listed in Smith, D.E. 1965, Late and postglacial changes of shoreline on the north side of the Forth valley and estuary.

Those with reference letters JBS are from unpublished records of J.B. Sissons.

APPENDIX B

HEAVY MINERAL ANALYSIS

High Buried Beach sample

NN 6529 0010

Garnet	62
Zircon	54
Chlorite	8
Hornblende	7
Tourmaline	2

Total count: 133 mineral grains.

Low Buried Beach sample

NS 7113 9778

Chlorite	89
Biotite	51
Hornblende	4
Garnet	3
Augite	3

Total count: 150 mineral grains.

Main Buried Beach sample

NS 8194 9591

Garnet	55
Zircon	37
Chlorite	22
Hornblende	16
Augite	6
Enstatite	5
Tourmaline	5
Apatite	2
Hypersthene	2

Total count: 150 mineral grains.

Carse-clay sample

NS 6800 9820

Chlorite	67
Garnet	29
Zircon	27
Hornblende	9
Augite	8
Enstatite	8
Staurolite	3
Epidote	2
Tourmaline	2
Biotite	1

Total count: 156 mineral grains.

APPENDIX C

POLLEN ANALYSIS OF BURIED PEAT AT WESTER KERSE

GRID REFERENCE. NN 6526 0001

STRATIGRAPHICAL INFORMATION. The sample was obtained from the lowest 2.0 cm of peat resting on the surface of the High Buried Beach.

<u>Arboreal Pollen</u>

Pinus	4
Betula	43
Alnus	1
Ulmus	3
Quercus	1
Corylus	21
Salix	22

Total arboreal count 95.

<u>Non-Arboreal Pollen and Spores</u>

Spores		Pollen	
Sphagnum	43	Gramineae	7
Filicales	6	Cyperaceae	3
		Filipendula	1

Total non-aboreal count 60

APPENDIX D

SUMMARY OF BURIED BEACH REGRESSION ANALYSIS DETAILS

1. HIGH BURIED RAISED BEACH

Menteith-Thornhill

Heights (in metres) 12.8, 11.1, 12.5, 12.5, 13.4, 11.1, 11.6, 11.1, 11.1, 11.2, 10.4, 11.4, 10.3, 13.2, 13.2, 13.1, 13.1

Total 17

$r = -0.3603$

Regression equation: $x = 13.2257 - 0.0197y$

Gradient = 0.197 m/km

Menteith-Thornhill (amended)

Heights (in metres) 12.8, 12.5, 12.5, 11.1, 11.6, 11.1, 11.1, 11.2, 10.4, 11.4, 10.3

Total 11

$r = -0.8788$

Regression equation: $x = 13.9549 - 0.0373y$

Burnbank

Heights (in metres) 10.9, 10.2, 11.1, 10.6, 11.1, 10.7, 10.6, 10.8, 10.7, 10.9

Total 10

$r = +0.078$

(Burnbank continued)

Regression equation: x = 10.3392 + 0.0033y

Gradient = 0.033 m/km

<u>Abbey Craig - Menstrie</u>

Heights (in metres) 9.9, 9.6, 9.1, 8.2, 9.8, 10.1, 9.4, 9.7, 9.6, 10.1, 8.7, 9.4

Total 12

r = -0.094

Regression equation: x = 9.5191 - 0.0056y

Gradient = 0.056 m/km

<u>Abbey Craig - Menstrie</u> (amended)

Heights (in metres) 9.9, 9.6, 9.1, 9.8, 10.1, 9.4, 9.7, 9.6, 10.1, 9.4

Total 10

r = -0.554

Regression equation: x = 9.8269 - 0.0168y

Gradient = 0.168 m/km

2. MAIN BURIED RAISED BEACH

<u>Menteith-Thornhill</u>

Heights (in metres) 12.1, 11.7, 11.3, 11.1, 10.6, 10.1, 10.0, 10.8, 9.5, 9.9, 9.3, 9.0

Total 12

r = -0.9487

Regression equation: x = 11.8398 - 0.0426y

Gradient = 0.426 m/km

Burnbank

Heights (in metres) 9.2, 8.9, 8.5, 9.8, 9.8

Total 5

r = +0.7862

Regression equation: x = 5.5623 + 0.0299y

Gradient = 0.299 m/km

Abbey Craig-Menstrie

Heights (in metres) 7.4, 7.2, 7.3, 7.3, 7.5, 7.0, 7.2, 7.2

Total 8

r = -0.2730

Regression equation: x = 7.3229 - 0.0053y

Gradient = 0.053 m/km

3. LOW BURIED RAISED BEACH

Menteith-Thornhill

Heights (in metres) 8.1, 7.8, 8.0, 8.2, 7.4, 7.4, 8.1

Total 7

r = -0.799

Regression equation: x = 8.4747 - 0.0116y

Gradient = 0.116 m/km

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THE STRATIGRAPHY AND SUB-CARSE MORPHOLOGY OF AN AREA

ON THE NORTHERN SIDE OF THE RIVER FORTH BETWEEN

THE LAKE OF MENTEITH AND KINCARDINE-ON-FORTH

David D. Kemp

Doctor of Philosophy

University of Edinburgh 1971

PREFACE

For many years now, the flat, low-lying land that extends up the Forth valley for 30-40 km from the Grangemouth-Kincardine area, has been of considerable interest to a variety of people, including geographers, historians, naturalists and agriculturalists. At different times, some groups have been more active in their investigations than others, but the net result has been an accumulation of literature on almost every aspect of these "carselands", as they are called, from lists of marine shells found in the carse-clay to the stories of the agricultural achievements of the "moss-lairds" of Blairdrummond.

In all this work, occasional reference may be found to the deposits underlying the carse-clay. Although not particularly numerous and often low in information value, these references give the first indications of a story that is in many ways more interesting than that of the carse itself, for recent investigation has shown that beneath the carse-clay lies a complete landscape, buried by the deposits of the Postglacial transgression.

The purpose of the present study is to examine the extent and nature of the buried landscape and to attempt an explanation of its various facets. Major elements of this landscape have been described as "buried raised beaches" and this terminology itself requires some explanation. Perhaps it would be technically more accurate to refer to these features as "buried raised estuarine deposits" due to their location in a former estuary of the Forth, but such a term is rather cumbersome. At the same time, the carse is commonly considered to be a major expression of the Postglacial "raised beach" sequence, although the carse-clay is mainly estuarine in origin. Thus there is a precedent for the usage and the term "buried raised beach" is employed throughout the thesis.

To place the present work in perspective, it should be noted that it is closely related to the work of J.B. Sissons and D.E. Smith on Late and Postglacial events -- particularly sea-level changes -- in the Forth valley and is linked to other studies of the same period in south-east Scotland carried out in recent years in the Department of Geography of the University of Edinburgh.

In the preparation of this thesis the writer has been aided by numerous people. He wishes particularly to express his gratitude to Dr. J.B. Sissons of the Department of Geography, Edinburgh University for his advice and encouragement throughout and his constructive criticism during the very important final stages of the work. He also wishes to acknowledge the very considerable help of Mr. Ian Kemp and Mrs. Patricia Kemp during the period of fieldwork and collection of data. At that time also, financial aid was provided by the Science Research Council, while the farmers and landowners of the carse allowed access to their property and companies and local authorities provided commercial borehole information. All of this is gratefully acknowledged.

The writer is also indebted to all who helped in the final preparation of the thesis, including Mrs. Marjorie Cameron and Mr. R. Cornell and especially Miss Elizabeth Wear who spent long hours carefully typing the various drafts and final copy. He also takes this opportunity to record his thanks to his wife for her encouragement and patience throughout. Finally, acknowledgements are due to the University of Edinburgh and Lakehead University for the materials and facilities they have provided.

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ABSTRACT

In an area on the northern side of the River Forth, between the Lake of Menteith and Kincardine-on-Forth, the stratigraphy of the carselands was investigated by hand boring, the results being augmented from commercial borehole records. From this, the morphology of the sub-carse deposits was determined and presented in maps and cross-sectional diagrams, for which heights had been obtained by accurate levelling. In addition, samples of the sub-carse deposits were subjected to laboratory analysis.

An examination of the evidence from these sources indicates a landscape, buried beneath the carse, consisting of areas of fine marine sediments forming raised beaches and areas of coarser sand and gravel. In the west, between the Menteith Moraine and Blairdrummond, fine marine sediments predominate and on the basis of variations in colour, composition and altitude they have been divided into three beaches, named the High, Main and Low Buried Raised Beaches. The beaches are closely associated with the Menteith outwash and the buried valleys of the Forth and its tributaries.

At Blairdrummond, the buried beaches end against the Teith outwash and are absent, except for small patches, as far as Stirling. They are replaced by a large asymmetrical fan of sand and gravel that originated largely as fluvioglacial material issuing from the Teith valley.

Beyond Stirling, sand and gravel deposits supplied by the Ochil streams and the River Devon are important in the buried landscape, but

all three buried beaches reappear, lying along the face of the Ochils, while in the vicinity of Kincardine-on-Forth a buried gravel layer is present. The latter is a product of marine erosion and includes areas of planated rock and till as well as gravel.

An examination of the morphological and stratigraphical relationships between the features, coupled with palynological and radiocarbon evidence, has allowed the determination of the following sequence of events. Close to 12,000 B.P., sea-level began to rise from a position slightly below present O.D. to reach a relative height of 10.0 m O.D. sometime during the halt of the Loch Lomond Readvance ice at the Menteith Moraine. During the rise, erosion produced the buried gravel layer. With the decay of the ice outwash was deposited at Menteith and also at Blairdrummond, while increased fluvial activity caused the formation or growth of numerous fans along the northern edge of the Forth basin. During this period around 10,300 B.P. the High Buried Beach was produced while later oscillations of sea-level caused the formation of the Main and Low Beaches, at successively lower altitudes, at about 9,500 B.P. and 8,800 B.P. respectively, before a final lowering took place close to 8,500 B.P. and the sea was confined to a relatively narrow estuary. The subsequent Postglacial submergence, reaching a maximum about 5,500 B.P., buried the earlier features beneath a layer of carse-clay.

Relationships between these events, local isostatic changes and world-wide eustatic changes were examined, rates of uplift being calculated and shoreline diagrams being produced. Uplift in the Forth fits presently accepted patterns, but the shoreline diagrams indicate a situation, as yet not recognized in other parts of

Scotland, in which variations in gradient take place along tilted shorelines. It is suggested that the search for features equivalent to the buried beaches in other parts of Scotland would help to clarify this and other problems associated with the changing positions of land and sea.

CHAPTER I

CERTAIN ASPECTS OF THE HISTORICAL GEOMORPHOLOGY OF THE FORTH VALLEY, WITH PARTICULAR REFERENCE TO THE RAISED BEACHES

There is nothing new in the observation that the seas around Britain have not always kept their "appointed limits". This has been fairly common knowledge for a long time now and seems to have some peculiar fascination for investigators, giving rise to ideas and fashions, as numerous as the sea-level changes from which they have sprung. No doubt the earliest inhabitants of the country were the first to notice and be affected by some of the changes taking place but, unfortunately, were in no position to leave evidence of their observations. Over the years, however, an extensive body of literature has grown up, based on a wide variety of information, from the discovery of human artifacts to the measurement of coastal landforms.

Scotland is particularly rich in this regard and within the country the Forth valley is well to the fore, as any examination of the literature will show. It was this area that gave birth to the concept which dominated the history of shoreline displacement for more than 80 years -- that of the 100 foot, 50 foot, and 25 foot raised beaches of the Geological Survey. Established in 1879 with the publication of Sheet 31 for an area in the vicinity of Falkirk, the many arguments over the presence or absence of this trio have caused the dissipation of tremendous energy. Much of the detail associated with this need not be repeated in the present context and in any case, has been comprehensively covered elsewhere (Sissons, 1962, 1963, 1965, 1967a; Smith, 1965; Walton, 1966). However, the Survey's 25 foot raised beach provides a useful datum from which the present study may proceed.

This raised beach was equated with the carselands of the River Forth, long recognised as being of marine origin from the abundant shells they contained (The Old Statistical Account of Scotland, 1791, Parish of Kincardine). As with similarly situated deposits on the northern shores of the Solway Firth and in the Clyde and Tay estuaries (Fig.I.1), the carselands of the Forth have had a variety of names applied to them. Although the Geological Survey, with its use of the term "25 foot Raised Beach" for the carselands, implied a feature with heights on its surface, at, or closely approximating 25 feet (7.6 m) and therefore virtually horizontal, neither was the case. This was not something that came to light after the Survey's classification of raised beaches, for several investigators prior to 1879 had considered the Forth carselands as a continuous morphological unit rising westwards up the Forth valley. As early as 1848, Chambers, in his "Ancient Sea Margins", had noted the slope of the carse, explaining it as due to removal of sediments in eastern areas when the sea lay at a lower level than it did when it deposited the carse. Later in 1865 and 1871 respectively, Jamieson and Milne-Home recognised the sloping nature of the carse, but these observations were lost in the general acceptance of the Survey classification.

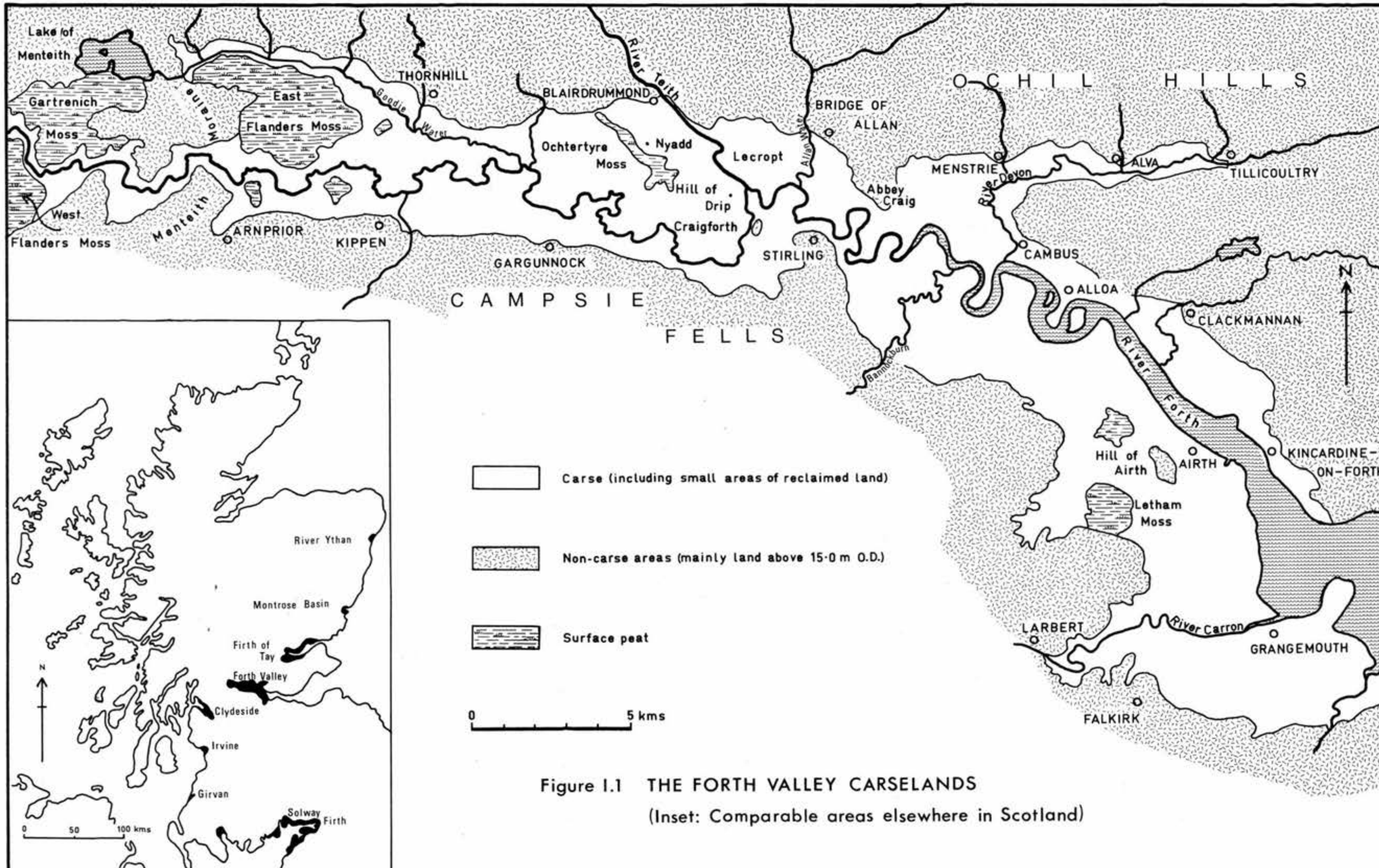


Figure I.1 THE FORTH VALLEY CARSELANDS
(Inset: Comparable areas elsewhere in Scotland)

Perhaps prompted by the difficulty of reconciling the idea of a 25 foot beach with the observable facts, J. Geikie in 1881 divided the carselands into 25 and 50 foot (7.6 and 15.2 m) raised beaches. Considerably later, in 1927, Dinham called them the 50 foot raised beach but by 1959 they had returned, in part at least, to the 25 foot bracket (Read, 1959). As might be expected, considerable confusion was one of the results. Further complications were introduced by archaeologists in the early part of this century when they began to refer to the carse and its stratigraphical equivalents as the "Neolithic Raised Beach". This line was followed up by Movius in 1942 when the abundance of *Littorina littorea* fossils in the so-called 25 foot raised beach prompted him to put forward the term "Littorina Raised Beach" for this feature. Such a trend away from the altitudinal designation of raised beaches can now be seen as a step in the right direction but two major papers in the 1950's helped to retrench the old ideas. In 1955, Charlesworth linked the orthodox interpretation of the Scottish raised beaches with glacial stages and in 1959, Donner, while recognising that the three-fold division did not always match observable facts, thought that for the sake of convenience no change should be made.

Although eminent geologists such as Jamieson and Wright had called the scheme in question it was only in 1962, after Sissons had rejected virtually all the preconceived ideas, that any real headway was made. As already pointed out, this has been fully dealt with elsewhere and need only be considered here as far as it applies to the so-called 25 foot raised beach. The latter term, as with those applied to the other raised beaches, became redundant as soon as accurate altitudinal measurements of the beaches were made and a new terminology was required. The shoreline of the former 25 foot raised beach in the Forth was found to record approximately the highest marine level of Postglacial times. This, together with the widespread nature of the associated deposits, led to its being named the Main Postglacial Shoreline or Beach, depending upon the context in which it was being used.

Following the formation of this raised beach, the level of the sea relative to the land began to fall towards its present position. That this was by no means completely smooth and continuous has been indicated by the presence of an additional three beaches lying lower than the main one. As a result, between Grangemouth and Stirling -- the area in which these lower beaches are best preserved -- a total of four Postglacial raised beaches has been differentiated, while west of Stirling all but the lowest of these have been recognized. In places, separation into different levels was only possible after careful altitudinal measurement, but in others a low, but distinct bluff could be seen marking the change from one beach to the other (Sissons, Smith and Cullingford, 1966; Sissons, 1967a; Smith, 1968).

Measurements along the shorelines of each of these beaches have shown that all slope eastwards with decreasing gradients from the Main Postglacial Beach through the other three (Fig.I.2). A figure of 0.4 feet per mile (0.08 m/km) has been calculated for the former, both north and south of the River Forth (Sissons, 1967a, Smith, 1968). The two middle beaches have produced very similar gradients close to 0.3 feet per mile (0.06 m/km), although on the

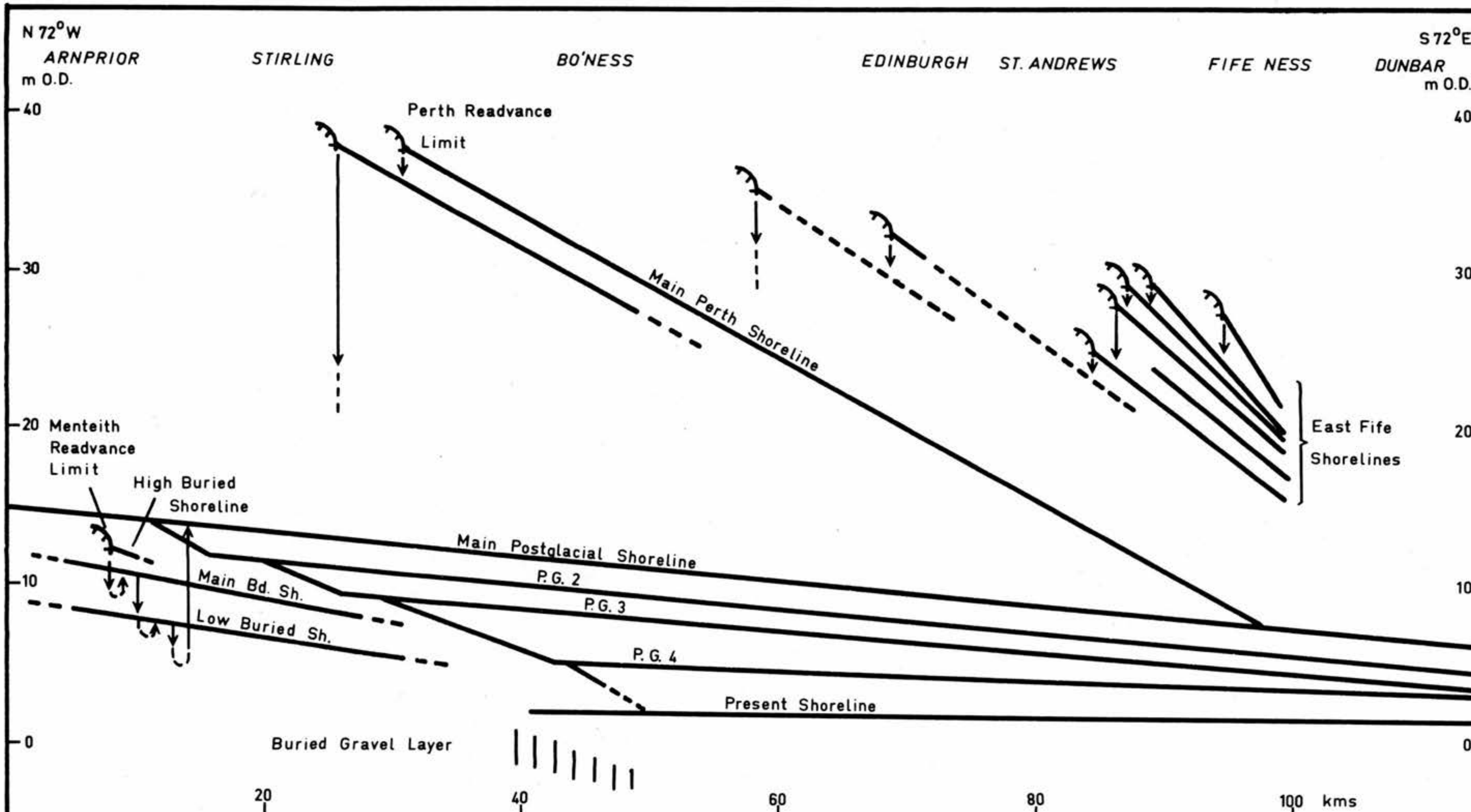


Figure 1.2 The raised shoreline sequence in Southeast Scotland (After Sissons *et al.* 1966.)

north side of the valley Smith has found the figure closer to 0.2 (0.04). In the case of the lowest shoreline, a further discrepancy arises, Smith's gradient value of 0.06 feet per mile (0.01 m/km) being less than half of the 0.17 feet per mile (0.03 m/km) quoted by Sissons.

Followed westwards, each shoreline gradient has been found to increase somewhat as the shoreline merges into the one above, pointing to sedimentation while the sea-level was actually falling as opposed to the times when, with respect to the land, it remained virtually stationary. The presence of occasional, very thin peat beneath the carse-clay of the lowest beach has been taken as indicative of a slight transgression, but as yet it is not known if the second and third Postglacial beaches were similarly formed. Thus, increased investigation makes it obvious that, from a geomorphological point of view, the carselands are much more complicated than was thought even relatively recently.

While all this energy was being expended on the carselands as raised beach deposits, little thought appears to have been given to the landscape that existed before the carse sea flooded over the area, covering some 70-80 square miles with deposits thick enough to completely mask the underlying topography. This did not mean that knowledge of what lay beneath the carse-clay was completely lacking, but the evidence was so limited in quantity, so variable in detail and so widely scattered that only very tentative conclusions could be drawn concerning the sub-carse deposits and their relationship to the overlying clay. The earliest recorded observations are to be found in the Old Statistical Accounts of the parishes that include part of the carse within their boundaries. Many, if not most, of the accounts refer to sections exposed by the Forth as it meandered through the area.

Unfortunately the writers of the Statistical Accounts were usually more interested in natural curiosities than in stratigraphical details. For example, the minister of the parish of Kilmadock or Doune noted trunks of oak trees, up to six feet in diameter, exposed beneath 20 feet of clay in the banks of the Goodie Water, a tributary of the Forth, but neglected to mention whether or not the underlying sediments were exposed. In the neighbouring parish of Kincardine the recorder was somewhat more explicit, writing that the carse "is a rich blue clay, beyond any depth that has been examined, excepting one corner, where a bed of gravel rises near the surface, as it approaches the Teath and dips towards the Forth at a rate of one foot in a hundred". Subsequent investigation by the present writer has shown the gravel to be of considerable extent. The account for Kincardine is one of the more informative, drawing attention to the lack of stones in the carse, and the absence of rock at, or near, the surface, "excepting in the eminences of Craig Forth, the Hill of Dript, and the Nadd, and for a small extent of the bed of the river at the cruives of Craig Forth and again at the Bridge of Dript". This chronicler also went as far as to suggest that the carse had been accumulated by the sea.

Detail such as this, limited though it is by modern standards, is useful, but is the exception rather than the rule. Most writers were content to note the unusual, such as the thick beds of sea-shells, the presence of whale skeletons, or the great thickness of carse-clay before rock was reached. In many places the superficial deposits did not consist entirely of carse-clay, but only in a few cases was any differentiation made. In 1841, the writer of the New Statistical Account for the parish of Logie, in Stirlingshire, pointed out that rock lay at 30 feet (9.1 m) below the surface in the northerly parts of the parish carselands, while in contrast rock-head could not be reached south of Abbey Craig. At the same time in Alloa parish the "carse" clay was said to be up to 90 feet (27.4 m) thick, although it seems certain that the term "carse" was used for almost anything that was not solid rock.

It would seem that the reports of the Statistical Accounts are of limited usefulness in most cases, but, until only recently, they provided the bulk of the information on the sub-carse deposits west of Stirling, where little commercial boring had been carried out.

Due to its flat, low-lying nature linked with the mode and time of formation, the surface of the carse proved an ideal situation for the growth of peat. Eventually peat mosses covered most of the area west of Stirling and certain sites east of the town. Most of this peat has since been removed, but fairly extensive areas still exist in the form of elevated mosses standing out above the surrounding cultivated land. On the north side of the Forth, the largest of these is East Flanders Moss, with smaller patches at Gartrenich, Blairdrummond and Ochtertyre (Fig.I.1). East of the Stirling gap, thin surface peat can be found at the back of the carse, where it abuts against the Ochils, but it seems certain that the eastern carselands did not support peat to the same extent as those farther west.

Where peat exists or has existed in this eastern area, its distribution can be related to the different carse surfaces. On the southern side of the river remnants of peat mosses still survive on the Main Postglacial Raised Beach, but there is no evidence for the presence of peat on the lower three. Compared with this, on the northern side, the Main Postglacial Beach is virtually absent and the peat here seems to have grown on the second highest raised beach, distinguished by Smith (1968) as Postglacial 2. The peat which remains is usually very thin, as in the vicinity of Blairlogie, but in the past it appears to have been as much as 7 feet (2.1 m) thick (The New Statistical Account of Scotland, 1841, Parish of Alva). As on the south of the Forth, there is no indication that peat ever covered the two lowest raised beaches.

During the late eighteenth and early nineteenth centuries great inroads were made into the mosses, hundreds of acres of good land being made available for agriculture. During the clearing operations, which are well described in the Statistical Accounts for Kincardine Parish and in Cadell's "Story of the Forth", many sections must have been exposed. Great ditches into which the peat was thrown, later to be flushed into the River Forth, still cross parts of the carse and although now overgrown with vegetation, sections can be re-exposed without too much trouble. It seems possible that the stratigraphy described for the Blairdrummond area by Jamieson (1865) and Milne-Home (1871), was first seen in one of these ditches.

In what is now regarded as a classic paper, Jamieson used the depositional sequence in the Blairdrummond area, along with sections from Tayside, Montrose Basin, and the mouth of the River Ythan, to establish the relative position of land and sea, in Scotland, in recent geological times. He noted the following section:

5. Surface peat.
4. Carse-clay with whale bones.
3. Peat with remains of trees.
2. Glacial Beds -- including marine beds on till.
1. Sandstone Rock.

From this Jamieson judged that, following the retreat of the ice that had deposited the till, the rising sea-level caused the marine beds to be laid down. With subsequent emergence, trees and peat grew on the newly uncovered ground only to be drowned when the sea-level rose again, depositing the carse-clay. Finally elevation raised the carselands to their present position, allowing the development of the area's great mosses. An essentially similar story had been outlined for the Tay estuary and the adjacent River Earn as early as 1841 by Buist, but it was only with Jamieson's consideration of a number of sites in Eastern Scotland that the broader implications became apparent.

A few years later, Milne-Home, writing about the Blair-drummond area, saw the buried peat as having been drifted into position rather than having accumulated *in situ*. Earlier writers had, however, shown it to be too extensive for this to have been the case and it had been pointed out that trees incorporated in the buried peat had roots penetrating into the underlying deposits (The Old Statistical Account of Scotland, 1791, Parish of Lecropt). The latter were the glacial marine beds of Jamieson, described by Milne-Home as bluish in colour and somewhat sandy in composition. James Geikie, writing in his account of "The Great Ice Age" (1894), considered these beds with their accompanying peat cover to represent the landscape that had existed prior to the deposition of the carse-clay.

This was virtually the sum-total of information available on the sub-carse deposits at the beginning of the present century. In the fifty years that followed, very little of direct relevance was added. However, changes were taking place in basic ideas of glacial advance and retreat and these have a greater bearing on the present investigation than is perhaps apparent at first sight.

Prior to 1914, many stratigraphical records were made available, especially east of Stirling, as mining companies sank numerous bores in search of coal. Some of these were used by H. M. Cadell in 1880 to examine the drift sequence in the Bo'ness area, and most of the information obtained was incorporated in his major work, "The Story of the Forth", in 1913. Although he did consider the superficial deposits, Cadell appears to have been more interested in the broader aspects of the geology and geomorphology of the Forth valley, spending considerable time, for example, in plotting the "pre-glacial" courses of the various rivers of the area. Finding evidence of drift lying on rockhead at some two and three hundred feet below sea-level, he inferred a great deal of river erosion while the sea lay well below its present level. Later bores showed even greater thicknesses of drift -- down to a maximum of 675 feet (205 m) below sea-level -- and present opinion, following that of Macgregor (1940) and Soons (1960), sees such deep buried troughs as being due to glacial over-deepening. Although the time of formation of these deep rock-basins has not been established absolutely, it is known that ice passed through this area several times and it is probable that the great depths were produced by the combined effects of more than one glaciation.

Relatively little is known about the earlier ice movements, but from the information available for the more recent period it has been deduced that a sequence of considerable complexity developed following the maximum of the last glaciation (Fig.I.3). As long ago as 1863 A. Geikie showed that a period of valley glaciation followed the decay of the last ice-sheet in Scotland. However, this was seen mainly as a temporary interruption in the fairly regular decay of the "mer de glace" and it was 1926 before the idea of ice-sheet readvance was introduced. In that year, Charlesworth described a major movement of Highland ice out over the Central Lowlands meeting ice covering the western and central Southern Uplands. An ice-limit was described as extending from St. Abb's Head, along the northern slope of the Lammermuirs, through the Tweed Basin and across the Solway lowlands to Stranraer. This limit and the features associated with it was referred to as the Lammermuir-Stranraer moraine. Later examination cast doubt on the inclusion of the central and eastern parts in the system while the northern section was linked with a readvance in the Aberdeen area to become the Aberdeen-Lammermuir Readvance (Sissons, 1961, 1965). Despite this, Charlesworth's paper was significant in that it introduced the readvance concept.

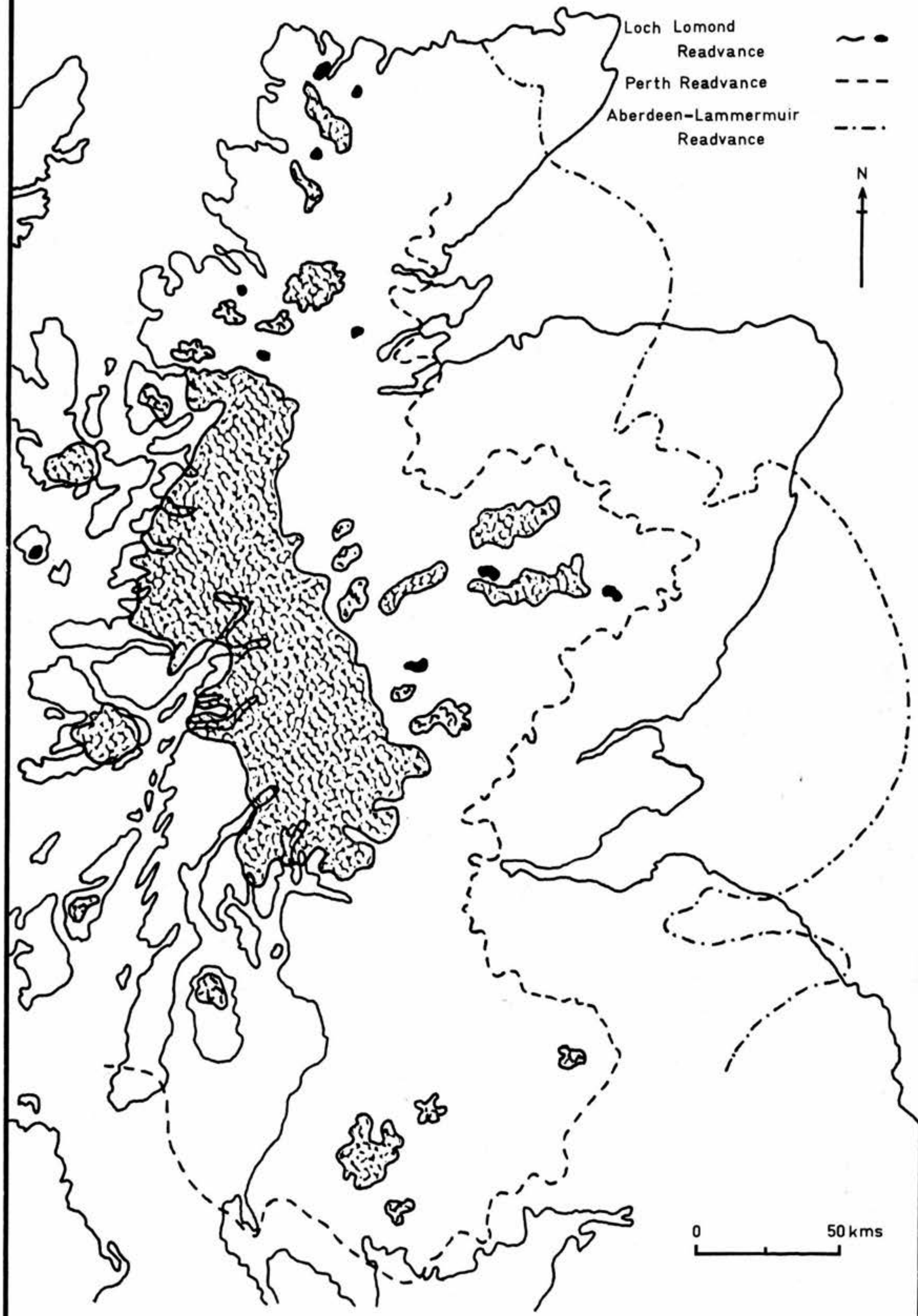


Figure 1.3 Successive limits of the last ice-sheet in Scotland

(After Sissons, 1967a.)

Following the postulated Aberdeen-Lammermuir Readvance, widespread deglaciation took place. It seems certain that glaciers did not disappear completely from the land and after a relatively short time they readvanced again. In this second case the ice was much less extensive, ice-streams from the Highlands, for example, reaching only limited areas of the Central Lowlands. The readvance was first demonstrated, in 1933, by J. B. Simpson in an area close to Perth in the Tay valley. Predictably it was called the Perth Readvance.

Evidence for this resurgence of the ice was provided by a section exposed a few miles northwest of Perth in the valley of the Almond, one of the tributaries of the Tay. Here, a layer of till, 12 feet (3.7 m) of which was exposed, was covered by a succession of 40 feet (12.2 m) of laminated clays and 15 feet (4.6 m) of sand and gravel. The finer sediments were considered to have been deposited following the retreat of the ice that had laid down the till and, from the measurement of some of the varves in these laminated clays, Simpson estimated that they had accumulated over a period of 640 years before the ice reasserted itself and produced the sands and gravels at the top of the section. Although they did not show the presence of ice at the site itself, these sands and gravels, being part of an extensive sheet of outwash leading down-valley towards Perth, recorded the return of ice to the vicinity and therefore completed evidence for a readvance.

Simpson found no such precise evidence for the readvance in the Forth valley, but from the distribution of morainic deposits and meltwater channels, he considered that ice had advanced in this area also. He saw the Forth and Teith glaciers coming together west of Stirling, the latter being diverted north-eastwards along Strath Allan to merge with the ice in Strath Earn, while the former passed through the Stirling gap and spread out eastwards. The exact position of the ice-front at this time could not be determined, but it was suggested that Glenfarg, a gap in the Ochils south of Perth, acted as a meltwater channel from south to north at this time. As a result, the ice was thought to have reached as far east as this. However, after consideration of sea-level changes, Sissons (1962) pointed out that the ice-margin was more likely to have extended only as far as the Stirling area and soon after Smith (1965) placed the limit of the Perth Readvance close to the present location of Kincardine-on-Forth.

While this ice was moving down the Forth and Tay valleys, similar glaciers were advancing down the glens of the Eastern Grampians and even larger ice streams were moving over Ayrshire and the Clyde Basin. Ice from the latter area passed around the southern edge of the Campsie Fells and into the valley of the River Carron, reaching the area where Larbert now stands (Simpson, 1933; Sissons, 1963). During the decay of this ice, meltwater carried great quantities of sand and gravel into the Carron and the Forth itself. For the most part, however, the activity of the ice in these other areas is of limited relevance here and as such requires only this brief mention.

With the decay of the ice, great volumes of outwash material were carried away from the receding ice-front and, in places, were built into the sea. Where this happened, outwash plains can sometimes be traced into raised beaches as continuous features. Subsequent isostatic uplift has caused these beaches to be raised well above sea-level and, in certain localities in both the Firths of Forth and Tay, they form rather conspicuous features, the most obvious of these having been termed the Main Perth Raised Beach (Sissons and Smith, 1965a). This beach would appear to have been formed when the ice was at its maximum extent or shortly after this, for it has been found to merge into outwash near Kincardine, Plean and Larbert, the limits of the readvance. Followed eastwards the Main Perth Shoreline declines at a rate of about 2.25 feet per mile (0.43 m/km) Fig.I.2 , from slightly below 125 feet O.D. (38.1 m O.D.) at Plean to 77-78 feet O.D. (23.5-23.8 m O.D.) at the Forth Road Bridge and 67 feet O.D. (20.4 m O.D.) at Burntisland (Sissons, Smith and Cullingford, 1966).

As the ice-margin retreated westwards, the meltwater streams continued to build up outwash plains and pour fluvioglacial debris into the sea. However, with variations in the relative rates of eustatic rise of sea-level and the isostatic recovery of the land, deposition did not take place at the same height as the Main Perth Beach. Since the level of the land in relation to the sea was rising these later beaches were formed at lower levels, as can be seen near Falkirk where two raised beaches at 84-88 and 108-109 feet O.D. (25.6-26.8 and 32.9-33.2 m O.D.) have been differentiated on the raised delta of the River Carron, while the Main Perth Beach stands at 116-119 feet O.D. (35.4-36.3 m O.D.). Followed westwards towards Stirling, the middle member of this series has been found to rise with a gradient similar to that of the Main Beach, reaching a height of almost 125 feet O.D. (38.1 m O.D.) before merging with outwash laid down when ice paused or even readvanced in the Stirling gap. Proof for such an assertion has been found in shoreline height differences east and west of the town. Immediately east of Stirling, the maximum altitude of the middle shoreline has been measured at 125 feet O.D. (38.1 m O.D.), but to the west the highest shoreline is only 73-76 feet O.D. (22.3-23.2 m O.D.) suggesting that ice stood in the gap long enough to witness a relative lowering of sea-level of 50 feet (15.2 m) (Sissons, Smith and Cullingford, 1966).

As well as the raised beach mentioned at 73-76 feet O.D. (22.3-23.2 m O.D.) to the west of Stirling, other fragments lie between 65-70 feet O.D. (19.8-21.3 m O.D.). For the most part, these are poorly developed or of limited extent and as a result correlation is difficult. Sissons (1967) has pointed out, however, that they are definitely absent from within the Menteith Moraine and therefore cannot have been formed after the moraine was built up.

When Simpson (1933) considered the movement of the Perth Readvance ice in the Forth valley, he admitted that a precise location for the ice-front could not be given. However, from general observations it seemed certain that the Forth glacier had extended beyond Stirling. In addition he drew attention to the presence of a well-marked moraine several miles to the west in the upper reaches of the Forth valley, indicating a further halt subsequent to the Perth Readvance. On investigation, it was found that the moraine not only pointed to a standstill, but also an advance of the ice-front. By consideration of glacially diverted rivers, it was possible to show contemporaneity between this moraine and a similar feature curving around the southern end of Loch Lomond. Both features were very distinct and sharply delimited, suggesting the possibility of a readvance and proof of this was supplied by the presence of shells in the moraines. Simpson named this second resurgence of ice, the Loch Lomond Readvance.

Although Simpson considered only the upper Forth valley and the Loch Lomond area, numerous writers have drawn attention to the existence of clearly defined, hummocky, morainic topography in many parts of the Highlands and Southern Uplands (J. Geikie, 1894; Wright, 1937; Charlesworth, 1955). The distribution of this hummocky moraine shows that the ice seldom spread out beyond the mountains at this time, pointing to the relatively small scale of the readvance compared with its predecessors. Despite this, evidence for the presence of the Loch Lomond Readvance is often more impressive than that of the earlier readvances.

Such is the case in the Forth valley, where, at its maximum, the Perth Readvance produced no morphological feature comparable to the very obvious Menteith Moraine of the Loch Lomond Readvance. Simpson (1933) followed the moraine for some 12 miles (19.2 km) from a point west of Buchlyvie in Stirlingshire in an arcuate loop across the Forth valley in the direction of Aberfoyle. From Buchlyvie as far as Arnprior the moraine comprises a series of mounds and ridges of sand and gravel, descending from a height of 800 feet O.D. (243.8 m O.D.) to almost 200 feet O.D. (60.9 m O.D.) at Arnprior, where the complex turns abruptly northwards. At this point, the moraine contains transported, shelly, marine clay. North of Arnprior, the system is broken by the River Forth, but beyond this it forms a conspicuous series of ridges, especially where it fronts the Lake of Menteith, reaching a height of about 100 feet O.D. (30.5 m O.D.). Here again, shelly marine clay is mixed with the more common sand and gravel. Near Port of Menteith, the morainic system turns sharply westwards, rising somewhat before dying out along the steep hill slopes (Simpson, 1933; Sissons, 1967a).

At its maximum the ice in the Forth valley pushed out into a sea that stood at 65 feet O.D. (19.8 m O.D.), according to Simpson. This value was inferred from the presence of marine clay at that height beneath the moraine, but it is now known that the clay is ice-transported, not *in situ*, and as a result Simpson's figure is no longer valid. However, an examination of the fluvioglacial deposits associated with the readvance has allowed another estimation to be made. Measurements on the surface of the outwash in the vicinity of the Goodie Water, the stream draining the Lake of Menteith, have shown a gradual altitudinal decline from 77 feet O.D. (23.5 m O.D.) down to 33 feet O.D. (10.1 m O.D.) where the gradient increases somewhat sharply. It was considered that this break at 33 feet (10.1 m), following the gradual decline from 77 feet (23.5 m), indicated the sea-level to which the outwash deposition was related. Similar measurements on outwash near Arnprior have indicated a possible sea-level at 37-38 feet O.D. (11.3-11.6 m O.D.). Both outwash plains must have been formed when the ice stood at the moraine, since the configuration of any ground exposed by a retreat would have disrupted the supply of meltwater and prevented their growth (Sissons, Cullingford and Smith, 1965; Sissons, 1966). Thus it would appear that at the time of the Loch Lomond Readvance the sea-level stood close to 35 feet O.D. (10.7 m O.D.).

Unfortunately, any evidence of features associated with such a sea-level has been hidden by later deposition. Indeed, the outwash plains referred to above were in part buried beneath carse-clay and peat, necessitating a considerable amount of boring before they could be located and measured. Perhaps due to difficulties of observation and perhaps due to a certain lack of interest, the interpretation of the buried deposits of the Forth valley proceeded only slowly. The work of Jamieson (1865), Milne-Home (1871) and Cadell (1913) has already been introduced and this provided the only information of any importance for a considerable length of time. It was only relatively recently, in the 1950's and particularly the 1960's, that this work was expanded to any extent.

In 1954, Parthasarathy investigated the superficial deposits of the Devon valley, part of the Forth basin, finding an essentially similar stratigraphy to that recorded by Jamieson farther west. In addition, he considered the texture, salinity and mineral content of the carse, concluding that it was of marine origin. At the same time a lower deposit, separated from the carse by a buried peat or gravel layer, was also interpreted as having been deposited in a marine environment.

He therefore recorded the following as a representative stratigraphy for the area:

5. Recent alluvium.
4. Carse clays.
3. Sands and gravels (or peat in places).

2. Lateglacial marine clays.

1. Boulder clays.

Although the findings were not completely unexpected, the methods with their emphasis on analysis and measurement were undoubtedly an improvement on much that had gone before.

At the other end of the carse, on Flanders Moss, a different approach was tried when Durno brought pollen analysis to bear on the deposits. He compared the stratigraphy at two sites, one at Blairdrummond similar to that examined by Jamieson, and one on Flanders Moss a few miles to the west. Deposition of the carse clay beneath the peat at Blairdrummond was considered to belong to the Atlantic climatic period, according to work carried out by Erdtman (1928). However, when Durno came to examine sediments lying below the thick peat of the Moss, he found heavy, bluish, silty clay which pollen analysis showed to be at least of Boreal age (Durno, 1956, 1958), and therefore having no correlation with the Atlantic period carse-clay of Blairdrummond. Since the latter was not represented in the Flanders Moss profile, the conclusion drawn was that the limit of the carse-sea transgression lay somewhere between the two sections examined (Fig.I.4). This was despite the fact that it had long been recognised that the carselands extended to the Menteith Moraine and beyond.

It was left to Sissons and Smith (1965b), to resolve the anomaly. Using boreholes put down by the Scottish Peat Survey and by themselves, they showed the existence of two roughly circular areas, in the western part of the Carse of Stirling, where carse-clay was absent and thick peat occurred instead (Fig.I.5). The

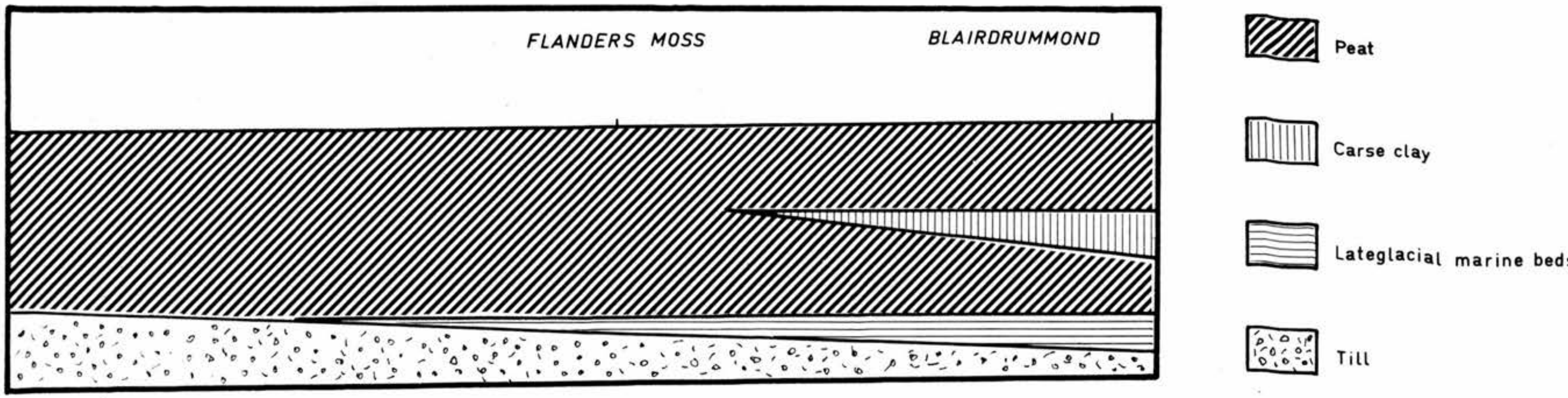


Figure 1.4 Superficial deposits in the Flanders Moss area, according to Durno (1958.)

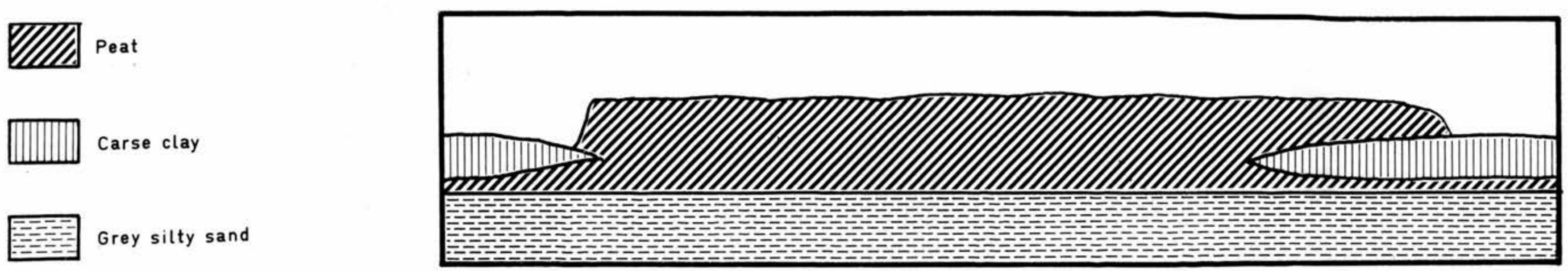


Figure 1.5 Superficial deposits in the Flanders Moss area, according to Sissons (1967a.)

latter lay on Lateglacial marine beds that were regarded as the sediments of a raised beach. Since this beach was completely obscured by later sediments, the term "buried raised beach" was coined. As the sea responsible for the beach retreated, it exposed an area, eminently suitable by reason of its subdued nature and poor drainage, for the growth of peat, which came to blanket almost the whole surface. When in turn the carse-sea transgression occurred, the largest part of the peat became buried beneath the associated carse-clay. However, in the two areas mentioned above, in East and West Flanders Moss, the peat, lying as it did at the head of the estuary and probably helped by isostatic recovery, was able to maintain itself above sea-level. In time, the carse-sea fell back and the mosses grew over the surface of the clay, obscuring the evidence for some 5000 years.

Although the above paper was mainly concerned with clarifying the situation with regard to the missing carse-clay, it also drew attention to the presence of a raised beach beneath the clay and peat. This was the first time such a name had been applied to the Lateglacial marine deposits.

Further work in the area (Sissons, 1966), brought to light the fact that the sub-carse peat lay at several different levels on surfaces that were flat or gently inclined and considered to represent beaches formed during periods of high sea-level in Late-glacial and Postglacial times. Three different beaches were identified, lying between 20 and 40 feet O.D. (6.1 and 12.2 m O.D.). Distinguished mainly by altitude, but also by the nature of their sediments, they were referred to as the Low, Main and High Buried

Beaches (Fig.I.6).

The High Beach was found only outside the Menteith Moraine and on the south side of the Forth where its shoreline was at an altitude of about 40 feet O.D. (12.2 m O.D.). In composition it was mainly pink silty sand with a thin cover of peat. The beach varied in width from 200-600 yards (180-550 m) and, followed away from the shoreline, it declined to about 36 feet O.D. (10.9 m O.D.) at its outermost edge. Here a slight bluff of a few feet separated it from the Main Beach, which was measured at 31-34 feet O.D. (9.4-10.4 m O.D.) along its shoreline and 28-31 feet O.D. (8.5-9.4 m O.D.) along its margin. This buried beach covered a large area both inside and outside the Menteith Moraine, its greatest extent being immediately east of the moraine on the north side of the river where it measured 1.5 miles (2.4 km) in a north-south direction and at least 2.5 miles (4.0 km) in a west-east direction. As in the case of the High Beach, peat covered this middle surface, but with thicknesses of at least a foot and often more, while the beach itself was composed mainly of fine, silty sand of light grey colour. Similar deposits formed the Low Beach except in the upper few feet which were sticky grey clay with stems of reeds extending downwards from the overlying peat. This lowest feature was found both inside and outside the moraine, at heights varying from 25.5-28 feet O.D. (7.8-8.5 m O.D.) in the first case and 21-25 (6.4-7.6) in the second. North of the Forth it was found to be higher, standing between 25.5 and 27 feet O.D. (7.8 and 8.2 m O.D.). Followed towards the Forth from both sides the Low Beach died out, usually quite sharply, and in a belt varying in width between 0.25 and 0.75

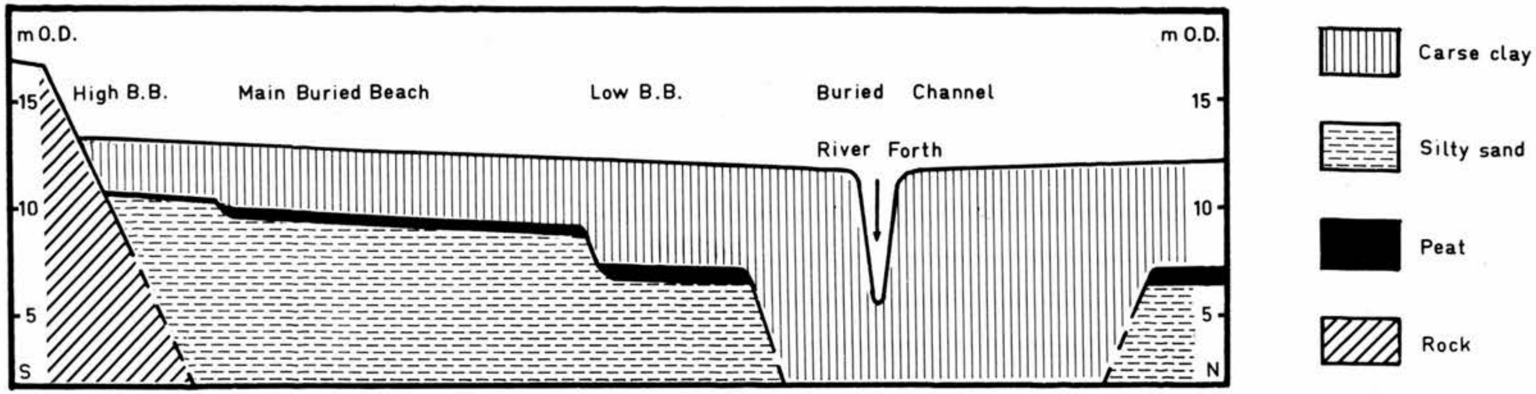


Figure 1.6 Buried beaches in the western part of the Carse of Stirling (After Sissons, 1967a.)

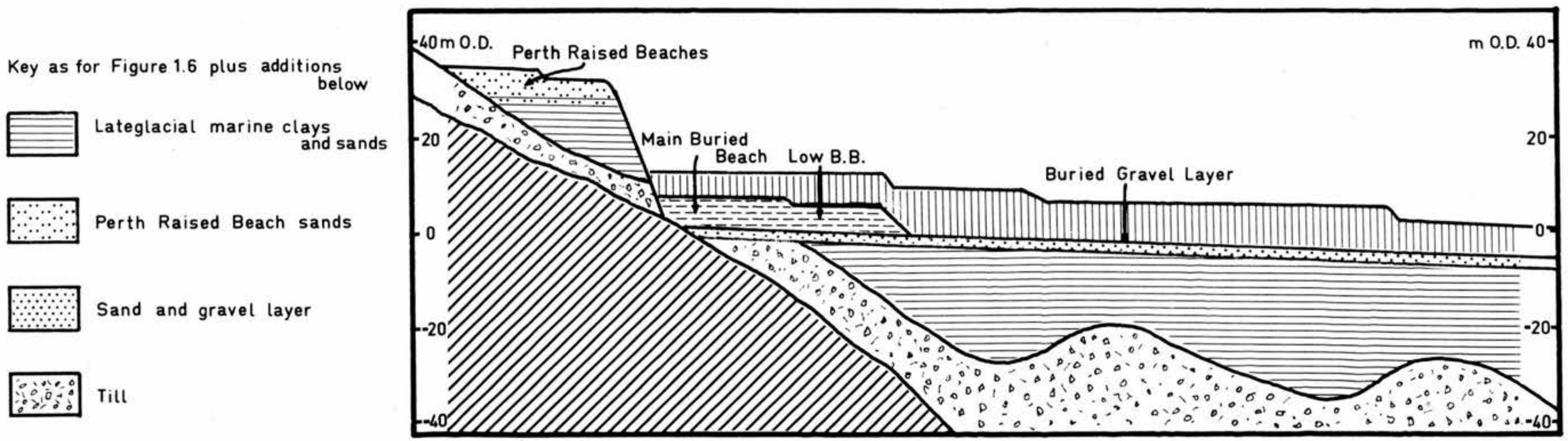


Figure 1.7 Superficial deposits in the Grangemouth – Airth region (After Sissons *et al.* 1966.)

miles (0.4 and 1.2 km) -- apparently following the trend of the present meander zone of the river -- no beaches were encountered and carse-clay alternated with layers of sand and sandy clay in which marine shells were found. It was suggested that this central belt was at one time an estuary in which sandy river deposits mixed with estuarine muds (Sissons, 1966; 1967a).

As well as being gently inclined towards the buried valley of the Forth, the Main and Low Buried Beaches were shown to have shorelines sloping gently eastwards as a result of isostatic tilting at a rate of 0.8 feet per mile (0.15 m/km) for the Main one (Fig.I.2) and a little less in the case of the Low. Both were traced down-valley, past Stirling to Bannockburn (Sissons, 1967a). The High Buried Beach on the other hand, was found only in a very limited area in the vicinity of the Menteith Moraine.

That portion of the carse to the east of Stirling, on the south side of the Forth and in particular, the area around Grangemouth, also proved conducive to further study. Numerous commercial boreholes, put down during site investigation prior to industrial development in the vicinity of the town, were supplemented by shallow hand-borings until an accurate picture of the stratigraphy of the area was built up (Sissons, 1969). The Main and Low Buried Beaches were again located, but perhaps the most significant element in the present context was an extensive layer of gravel. It varied in thickness from a few inches to 5.0 feet (1.5 m) rising gently from about minus 20.0 feet (6.1 m) to approximately Ordnance Datum and then rising more rapidly to as much as 20.0 feet (6.1 m) above sea-level in places. Its composition of rounded stones and sand intermixed with marine shells, suggested a further buried beach but it bore no similarity to those already referred to, for the latter were composed mainly of fine sediments. Sissons saw the buried gravel layer as indicating a period of marine erosion, his supposition being supported by the presence of marine cliff forms at the outer edge of the Perth Raised Beach deposits and the existence of planated rock and till surfaces beneath the carse-clay. Erosion of rock, till and the Lateglacial marine deposits (the last containing much ice-rafted debris), appeared to have provided material for the beach now represented by the buried gravel layer.

Important as the gravel layer was in its own right, showing a hitherto unrecognised period of extensive marine erosion, its position with respect to the other deposits proved rather significant. Traced landwards from the Forth it was found to pass beneath the sediments of the other two buried beaches in the area, thus indicating relative ages (Fig.I.7). Older then than the Low and Main Buried Beaches, it could be shown to be younger than the Perth Raised Beaches, since the associated cliff truncates the latter. Thus, in terms of relative age, the buried gravel layer could be located with considerable certainty.

This raises the whole question of dating, so far only touched upon in a very general way. Indeed, general relative dating was really all that was available to the early workers. It is only recently that the techniques of pollen analysis and radio-carbon dating have allowed present-day investigators to become much more specific than their predecessors.

With regard to the present investigation, most of the stratigraphical elements mentioned above have been supplied with absolute dates, or have been related to known dates. In considering these it is probably best to start with the youngest units, which are also perhaps the most obvious, and work backwards.

The presence of peat in the Forth valley helped dating considerably. Pollen analysis from Ochtertyre Moss showed that the peat, overlying the carse-clay here, began to accumulate during the late Atlantic climatic period (Erdtman, 1928). Radio-carbon measurement at a later date from nearby Flanders Moss gave a figure of 5,492 ± 130 B.P., for the base of the peat (Godwin and Willis, 1962). Despite a slight discrepancy, these results were generally taken as confirming each other and since they refer to the base of the peat, must also give a date by which the carse-clay had ceased to accumulate. Using similar techniques, it proved possible to investigate the buried peat to obtain the time at which the carse-sea transgression began. At Airth, between Stirling and Grangemouth, the top of the buried peat was carbon dated at 8,421 ± 157 B.P. (Godwin and Willis, 1961). Comparing the two dates, a period of some 3,000 years is obtained during which carse-clay was deposited.

More recently this relatively simple explanation has been revised somewhat and it is now recognised that the carse-clays form four Postglacial shorelines (Smith, 1965; Sissons, 1967a). Smith (1968) used this fact to explain the slight age difference between the peat at the base of Flanders Moss and that at the base of Ochtertyre Moss. In the former case the peat was considered to lie on the Main Postglacial Raised Beach, while in the latter it lay on a lower and slightly younger beach. With two additional beaches at lower levels, it seems likely that the carse-clay accumulated for more than 3,000 years and a date of approximately 4,000 B.P. has been estimated for the third beach in the series (Sissons, 1967a). In addition, localities in the southwest of Scotland have produced radio-carbon dates that show the formation of the Main Postglacial Beach there, to have been earlier than in the Forth valley. At Lochar Moss and Newton Stewart, dates of 6645 ± 120 B.P. and 6159 ± 120 B.P. respectively, have been obtained from deposits overlying the stratigraphical equivalents of the carse-clay showing the earlier retreat of the transgression from its maximum, in this area (Godwin and Willis, 1962).

Using such techniques, care must be taken in the choice of horizon from which samples are taken, especially if dates of sea-level change are to be inferred from the results. Although dates obtained from buried peats in Scotland are relatively numerous, the fact that they have been collected without too much attention to this, means that they are less useful than they might have been. Partly as a result of this and partly because the buried peat is not all of the same age, in any case, carbon dates from the buried peats cover a fairly wide range.

The oldest of these buried peats was measured in the Solway Firth, at Redkirk Point, between Annan and Carlisle, where a bed of peat gave an age of 12,290 ± 250 years (Godwin and Switsur, 1966). At the same site, a peat bed slightly above this one and approximately at present sea-level, was estimated at about 10,300 years old. In the west and southwest generally, the peat appears to be older than in the east. In the former, dates of 9,620 ± 150 B.P.

at Irvine, 9,362 ± 150 B.P. at Girvan and 9,640 ± 180 B.P. at Brighouse Bay, in Kirkcudbrightshire, can be quoted. One exception to this trend is a date of 8,135 ±150 B.P. at Redkirk Point in Dumfriesshire (Godwin and Willis, 1960-62). In contrast, the dates for localities further east tend to be later. For example, in the Earn Valley at Eastfield of Dunbarney and Broombarns, dates of 8,421 ± 157 B.P. and 8,354 ± 143 B.P. respectively have been obtained. The figure of 8,421 ± 157 B.P. for Airth can also be noted here (Godwin and Willis, 1961). Exotic results, such as the Geological Survey's dates of 3,249 ± 160 B.P. for the peat/carse boundary in the Forth valley and 3,656 ± 150 B.P. for sub-carse gravel in the Teith valley indicate further that although radio-carbon dating is a great advance on other techniques, it may present new problems of interpretation.

Returning to the more particular problems of the Forth, the dating of the buried beaches can be approached from a consideration of the peat that intervenes between them and the carse-clay. Before the idea of buried raised beaches had been formulated, it had been shown by pollen analysis that the glacial marine beds in the Flanders Moss area were of Boreal age (Durno, 1956). The location of these sediments placed them in what was later called the Main Buried Beach and from the analysis it was inferred that the age of the feature was around 9,500 years (Sissons and Smith, 1965b). Using similar methods, but with a greater knowledge of the sub-carse deposits, this date was confirmed by pollen analysis of peat at another point on the beach (Newey, 1966). Working through the uppermost sediments of the beach itself and into the lower few centimetres of the peat, Newey noted the presence of *Chenopodiaceae* and *Gramineae* pollen, which he considered to indicate salt-marsh conditions. This showed not only the marine origin of the buried beach but also pointed to the fact that the peat had begun to grow while the sea was still vacating the beach. Thus, when the base of the peat lying upon the Main Buried Beach was shown to belong to the transition between Zones IV and V of the pollen sequence, corresponding to an age of about 9,500 years, this figure could be taken as the approximate age of the beach itself.

In the same way, Newey proved the marine origin of the Low Buried Beach and showed it to have been formed wholly during Zone V. In this case the date was verified by the radio-carbon method which gave a figure of 8,690 ± 140 B.P. for the peat immediately above the beach. The result did not agree with dates from comparable situations in England and Northern Ireland, being slightly younger (Godwin and Willis, 1965). It was thought possible that there might be a lack of exact synchronisation between pollen zones in the Forth valley and the areas mentioned. However, in the peat above the Low Beach there were numerous tree-trunks and branches and it seemed that these trees, growing at a later date than the basal peat, might have sent roots down into it, thus slightly reducing its apparent age. Bearing in mind also that the peat had to be slightly younger than the surface on which it grew it was suggested that the Low Buried Beach ceased to be formed about 8,800 years ago (Sissons, 1966).

While carrying out pollen analysis of the peat overlying the Low Beach, Newey (1966) had noted marine influences in the lower layers indicated by the presence of *Gramineae* and *Chenopodiaceae* pollen. Followed upwards these types of pollen were replaced by the normal freshwater swamp and arboreal pollen, such as *Sphagnum*, *Salix* and *Betula*. Near the top of the peat layer salt-marsh pollen was again found, pointing to the return of marine conditions. The succession showed the lowering of sea-level after the formation of the Low Beach, when the sea became restricted to the buried estuary, and its eventual return to produce the carse-sea transgression. By obtaining dates from the base of the peat and from the top, it was possible to estimate the length of the period during which the buried estuary was occupied. As already noted, the Low Beach was vacated about 8,800 years ago. Radio-carbon measurement of a sample taken where the peat began to merge with the overlying carse clay, gave a date of 8,270 ± 160 B.P., by which time the rise in sea-level, that produced the carse, must have been in progress. Taking the two dates together, the sea occupied the buried estuary for approximately 500 years and it was suggested that a minimal sea-level during this time was reached about 8,500 years ago (Sissons, 1966).

Such techniques of pollen and carbon-dating could not be used in the case of the High Buried Beach, due to the paucity of peat on its surface. However, by reference to a previously dated feature, the Menteith Moraine, an approximate figure was obtained. Unlike the other buried beaches, the High Beach was not encountered within the moraine, which suggested that it accumulated while ice was still present. On the other hand, the sediments of the beach were discovered lying immediately above outwash gravels near Arnprior, showing that the High Beach was formed after the outwash deposits were laid down. The evidence therefore restricted the formation of the beach to a period after the construction of the moraine and associated outwash, but before the retreat of the ice from the moraine.

By comparison of pollen zones present outside and inside the limits of the Loch Lomond Readvance, Donner (1957) had placed the formation of the moraines in Zone III of the pollen sequence. Confirmation of this was obtained from radio-carbon dates of shells in the Loch Lomond and Menteith Moraines which gave figures of 11,700 years and 11,800 years respectively. In the case of the Forth, this implied that the sea extended to the head of the low-lands during Zone II, its deposits being redistributed by the Menteith glacier and incorporated in the moraine during the Zone III cold phase. With this additional evidence, the Zone III readvance was confirmed, giving a date for the formation of the moraine in the vicinity of 10,300 B.P. Bearing in mind the stratigraphical relationship between the moraine and the High Buried Beach, it was suggested that the latter was produced at, or shortly after this time (Sissons, 1967a).

The dating of the buried gravel layer was approached in a similar fashion. As already indicated, the stratigraphy showed it to have been formed sometime after the Perth Readvance Raised Beaches but prior to the Buried Beaches, which gave limiting dates of 13,500-13,000 B.P. -- the present provisional date for the culmination of the Perth Readvance -- and 10,300 B.P. -- the date of formation of the High Buried Beach (Sissons, 1967a). Such a period of 3,000 years is very different from the more precise dates for the formation of other features, but with the relatively limited evidence available at present greater precision is not possible.

In conclusion, it should be pointed out that of all these features, only the Menteith Moraine and the carselands form elements of the landscape in the area covered by the present study. Comparing the dates of formation of the two, it can be seen that some 5,000 years lie between the time when ice stood at Menteith and the time when the carse-sea began to fall back from its maximal limit. Evidence of the geomorphological activity of these years now lies beneath the carse, but in the course of the following chapters it is hoped that the carse-clay can be metaphorically removed to expose the landscape beneath.

CHAPTER II

METHODS EMPLOYED IN THE PRESENT STUDY

Many, if not most, of the early stratigraphical records of sub-carse deposits in the area adjacent to the River Forth were obtained from chance exposures observed when streams were low or when deep drainage ditches were dug at the time of the moss-clearances. With the advent of commercial boring, knowledge of the stratigraphy was increased greatly in certain areas, but the overall coverage remained very limited, restricting any interpretation that might be attempted. To remedy this, a comprehensive boring programme was begun by J. B. Sissons in the western part of the Carse of Stirling, the methods used being described in the Institute of British Geographers' special publication on shoreline displacement (1966). The present survey follows similar lines, but, in addition, introduces laboratory analysis of the sub-carse deposits. With this in mind, the methods can be described in terms of those used in the field and those used in the laboratory.

Methods of Fieldwork.

Boring. The basic fieldwork was carried out using a hand-borer, modified from the Hiller-type peat borer by the addition of steel bands at the extension-rod joints. With this it was theoretically possible to reach a depth of 10 m from the surface, but in practice this was either seldom required or impossible to reach due to the tough nature of the deposits. The toughest part of the carse itself was usually the top metre which was removed with a normal soil auger before the Hiller borer was inserted. Within the area studied, this layer of tough clay -- the carse-crust -- varied in thickness, apparently as a function of drainage. In well drained arable land, near ditches and streams or in areas underlain by gravel, the crust increased in thickness to almost 2.5 m in places, making boring very difficult. On the other hand, where the carse was badly drained, near the remnants of the once extensive peat mosses, the crust was very thin and beneath the peat itself, usually non-existent.

Individual borehole depths varied considerably, from less than 1.0 m to a maximum in excess of 8.0 m depending upon several factors. The greatest depths were reached in bores which passed down into the buried valleys underlying the Forth and most of its tributary streams. In the Devon valley, a maximum of 8.9 m was reached while holes beside the Goodie Water and the Forth itself commonly produced depths in excess of 6.0 m, compared with the general average of 3.5-4.0 m. Deeper holes were also required where peat was present on top of the carse-clay. These reached figures of 7.5-8.5 m on Flanders Moss, the upper stratum being entirely peat 3.5-4.5 m thick.

Since the deposits lying beneath the carse-clays were being investigated, the thickness of these clays and the depths of particular boreholes showed a marked relationship, strengthened by the fact that, in most cases, the sub-carse deposits proved too tough for penetration with the equipment available.

In the first phase of fieldwork, lines of boreholes were put down at varying intervals across the carse, in a north-south direction, in an attempt to establish a general stratigraphical pattern. The spacing of the boreholes varied from as little as 5 m to as much as 200 m, although 50 m intervals were most common, giving reasonable accuracy as well as ease of measurement both on the ground and on paper. The smaller intervals were necessary for accurate delimitation in areas of rapid horizontal change in the sub-carse deposits and were required in the location of the shorelines of what proved to be buried marine features.

With the completion of twelve such traverses, the basic distribution had begun to emerge. To supplement this pattern, a further series of borings was made with two main aims; firstly, to provide links between adjacent traverses at the same time filling in the broader picture and secondly, to allow some statistical examination of the buried landforms, for which careful selection of borehole location was necessary. For example, in the second case, short lines of closely spaced bores in certain areas enabled buried shorelines to be recognised. With accurate heighting, these could be related to former sea-levels and any warping since formation could be measured. Again, where the bores were relatively numerous, and after heighting, it was possible to draw formlines to give a reasonable representation of the surface shape of the deposits.

The borehole logs obtained from this programme are listed in Appendix A.

Levelling. As already mentioned, the results of boring were used to show the position and height of former shorelines. It has been established that for this information to have any real meaning accurate heighting is a primary requirement. Different methods are available, depending very much on individual intepretations of the word "accurate", but, for the purposes of this study it was decided to measure all heights by levelling. Two facts prompted this. In the work already done on the sub-carse deposits of the Flanders Moss area all heights were the result of levelling. Continuity and comparison, therefore, demanded similar methods in this present work. Furthermore, with the Hiller borer it was possible to achieve an accuracy of 1-3 cm in the measurement of stratigraphical boundaries. To take proper advantage of this fact, any instrument or combination of instruments less accurate than a surveyor's level and staff could not be considered.

All levelling was carried out with reference to Ordnance Survey bench-marks or to temporary marks derived from these official heights, and all traverses were closed. From the figures produced, the closing error was calculated, the aim being to keep it as low as possible in relation to the length of traverse, although variation did occur within a range of 0.00 feet to 0.60 feet. Higher figures such as the latter were allowed in certain instances, for example, over the buried valley of the Forth, where slightly less accuracy could be tolerated, but in most cases the closing error did not exceed 0.10 feet. The original altitudes in feet derived from the levelling were converted to metres for ease of comparison with the metric calibration of the Hiller borer and to coincide with recent trends towards the adoption of the metric system in studies such as this.

In the area east of Stirling, it was found that certain bench-mark heights did not agree with the published figures due to extensive mining subsidence. This difficulty was overcome by using heights measured by D. E. Smith (1965) and corrected to the Fundamental Bench-Mark at Menstrie. A further check, made by comparing these heights one against the other, enabled obvious differences to be taken into account.

A few boreholes - less than a dozen - were not levelled, where the distribution of a particular deposit was considered more important than its height.

Refraction Seismography. As a possible supplement to boring, some consideration was given to the investigation of the sediments of the area by means of a portable refraction seismograph -- a Soiltest Terra Scout. At first sight this appeared to provide a simple and rapid method of sub-surface survey. However, there proved to be several inherent difficulties. The apparatus comprised the Terra Scout itself (basically an oscilloscope tube) a geophone and a tamper, the latter objects being connected through the receiver in such a way that shock waves generated by the tamper were picked up by the geophone, to be converted into a wave pattern on the receiver screen. From this, the time taken for the shock waves to travel from the tamper to the geophone was obtained by fixing an adjustable reference point on to a chosen position on the wave. When the two points had been made to coincide, the time required, in milliseconds, could be read from a graduated counter on the face of the receiver. By varying the distance between tamper and geophone from 2.0 m to 50.0 m, a series of times could be built up and plotted on a time/distance graph, which could be shown to contain a number of facets. The exact number depended upon the various strata through which the shock waves had passed. In turn, the gradient of each facet could be measured and by reference to a nomograph the rate of passage of the shock waves through each stratum could be calculated. Similarly, the depths at which changes in the stratigraphy occurred could be obtained. The final step was to identify the various strata, which was made possible by the ability of different rock types to allow the passage of shock waves at different rates. By simple comparison with prepared tables the elements of the stratigraphy could then be identified.

Although reasonably simple in operation, the refraction seismograph had certain drawbacks as far as the present investigation was concerned. In the first place, it required two persons for its use compared with the one necessary for hand boring. Such a difficulty was by no means insurmountable, but in several other respects the seismograph compared badly with the borer. One of the primary principles of seismic work is that density of the deposits being investigated increases with depth. As it happens, in the area of the carselands such a requirement cannot always be met due to the presence of buried peat. Seismic survey could still be carried out, but the peat, being overlain by denser carse-clay would not be recorded - an omission of considerable proportions when it is noted that this sub-carse peat can be as much as 1.5 m thick. Apart from this, the stratigraphy as a whole could not be so accurately represented by the seismograph. Depending upon sub-surface conditions errors of up to 0.3 m could be expected compared with the few centimetres possible with the Hiller borer. Furthermore, when identifying the deposits from their velocity figures a certain amount of overlap occurred. For example, the following are typical values for some rock-types to be found in the area under study.

Sandy Clay	1,200-1,900 ft/sec.
Gravel	1,600-2,600 ft/sec.
Glacial Till	1,800-7,000 ft/sec.
Sandstone	3,000-9,000 ft/sec.
Shale	2,600-11,000 ft/sec.

In such a situation, it would be necessary to put down check boreholes which would virtually double the time taken at any one site.

Perhaps the main asset of the refraction seismograph was depth of penetration which could be 3 or 4 times greater than that possible with the Hiller. However, taking the factors already mentioned into account, it would appear unwise to place too much emphasis on seismic survey without borehole control. Where boring was relatively easy, as in the case in question, it was doubtful if seismic work added substantially to the information obtained by the former method. Thus, following some initial work for comparison with boring, no additional seismic surveying was carried out.

Commercial Boreholes. As a further source of information, the logs from a large number of commercial boreholes, ranging from well-sinkings to site investigation probes, were acquired. These proved to be of mixed usefulness. In a study where accurate heighting was important, the complete absence of heights in many cases was somewhat disconcerting. In addition, there were reports carrying no locational details. At the other extreme were holes, numbering no more than fifty, which in location, height and detail compared very favourably with those bored with the Hiller. All in all it was apparent that the bulk of the commercial bores had to be used with extreme care and where possible in conjunction with accurate hand boreholes.

These, then, were the methods used in the field. They were related to laboratory work through the collection of sediment samples which were analysed by the methods indicated below.

Laboratory Methods.

Before any laboratory analysis could be carried out, samples had to be collected and prepared. This in itself gave rise to several problems, not the least of which was the determination of points from which samples were to be obtained. It was not possible to use a purely objective pattern of sampling (e.g. every third borehole) since the nature of the buried landscape was not apparent until a certain amount of boring had been done. Dependence on such a scheme would have involved continual duplication of effort. Ideally, the problem could have been solved by sampling from every stratum in every hole, but the drawbacks in terms of time and volume of material were obvious.

After the completion of several traverses, it had become increasingly apparent that major differences did exist in the sub-carse deposits with regard to colour and texture, but at the same time, within these units, large areas of remarkably uniform sediments were also present. It was therefore decided that a relatively flexible pattern would be adopted, based on samples taken wherever deposits in adjacent holes showed change in colour or composition. To supplement these, further samples were taken at random with the aim of examining the uniformity within particular sedimentary units. Thus, the sampling system is almost entirely empirical, chosen for the information it might provide on the similarities and differences already partially recognisable by visual inspection.

Apart from the initial problem of deciding upon the distribution of samples, there were further difficulties, mainly of a mechanical nature. Firstly, the sub-carse deposits often proved too tough for penetration to the full extent of the Hiller sample chamber, making it difficult to collect a reasonable size of sample. Any attempt to increase this by a second extraction from the same hole was virtually useless, for as soon as the borer was removed for the first time, liquid carse-clay and peat flowed to the base of the hole to contaminate any subsequent sample. This difficulty also meant that results from many of the samples referred only to the top 20-30 cm of the deposits.

Secondly, where the underlying deposit was gravel, no sampling was usually possible unless the constituents were very small. However, with experience, some indication of the nature of the gravel could be obtained from the effect it had on the Hiller. Big gravel, for example, locked the borer fast, whereas smaller gravel allowed a certain amount of movement but little penetration, and gravel mixed with sand permitted the occasional sample.

Added to the samples from the sub-carse deposits were a number from the carse itself, collected for purposes of comparison.

Almost 100 samples were obtained and all were air-dried on porous plates before being ground and sieved. Sieving in the first instance was through a 2 mm mesh and it was noted that, in most cases, the whole sample could be passed through the sieve, giving an indication of the fine nature of the deposits with which the investigation was concerned. The dried, sieved sediments which resulted from this preparation were stored in labelled glass jars.

Analysis for pH. Simply defined, the value quoted for the pH of a soil sample is the measure of the hydrogen ion concentration in that particular sample. The basic theory behind this is in part rather complicated but experience has shown that a simple scale derived from this is adequate for most purposes. On the scale, the value 7 stands for neutrality, higher figures indicating alkalinity and lower acidity, with an unbroken range of possibilities in between.

All samples collected in the present study were measured for pH using a Cambridge Direct-reading Meter, calibrated for buffer solutions of pH 4 and pH 7. Comparison of the unknown samples with these solutions of known value gave the required results and the use of two buffers allowed a check to be kept on the figures obtained. Additional cross-reference was attempted by variation of the fluid suspensions from which the readings were taken. All samples were measured in distilled water initially. However, under normal conditions, the water contained in sediments is not pure, but contains salts in solution. It was therefore decided to take further readings from samples in a solution of calcium chloride, the salt most commonly used to simulate the natural situation. In the final analysis, these were the results used and the figures obtained with distilled water were kept merely as a check.

Analysis for organic carbon. One of the more obvious differences between the carse-clay and its underlying deposits concerns the organic content of each. It has long been known that the carse-clay contains abundant vegetable matter as well as numerous shell beds. In contrast, both are apparently lacking in the sub-carse deposits except in the uppermost parts where there is mixing with the overlying peat. Although obvious by inspection alone, an attempt at quantification was made. This proved unsuccessful for several reasons. In the first place, although the organic content of the carse-clays is high over the carse as a whole, it is mostly arranged in thin beds or lenses. As a result, small samples, such as those common in this investigation, could, and did, give widely differing results. A second source of error lay in the sampling of the sub-carse deposits. As indicated, in the majority of boreholes it was only possible to sample the top 20-30 cm. Where this was so the figures obtained for organic carbon content could not be considered representative, for at that depth in the deposit contamination by roots, stems and other vegetable matter from the overlying peat, was often considerable. In the sediments obtained from sections or the occasional deeper bore, the organic carbon percentages were very low, but these samples were not sufficiently numerous to allow definite conclusions to be drawn.

Particle-size analysis. With the completion of several borehole traverses, it became increasingly obvious that the subcarse deposits were falling into broad patterns judged in terms of mechanical composition. Seemingly significant differences occurred, often quite sharply, between adjacent sites, but, as already noted, over large areas the uniformity of the sediments was quite remarkable. To examine these two aspects and to give them some quantitative basis, particle-size analysis of the various samples was carried out.

There were several methods of analysis available, ranging from sedimentation balances with automatic recording equipment or the pipette method with its fine adjustment to the simple routine hydrometer methods and more crude sieving techniques. After consideration of the equipment required and the balance to be struck between accuracy and ease of working, it was decided to use the hydrometer method.

Hydrometer analysis was carried out on that fraction of the sample which passed through a 2 mm mesh sieve. A known weight of the material was first treated with hydrogen peroxide to remove any organic matter that might give rise to flocullation and consequent false results in the sedimentation analysis. The sediments were then dispersed in a dilute aqueous solution of a deflocullating agent and allowed to settle. As settling took place, hydrometer measurements were recorded at varied but calculated intervals and the rate at which sedimentation took place was determined by the rate of decrease in density of the upper part of the liquid as the particles settled out.

The method depends on the fact that particles of different sizes have different settling velocities. With the aid of a nomograph based on this fact, the velocities of the particles were measured and their equivalent diameter computed on the assumption that they were spherical in shape. The results obtained for each sample were plotted on a semi-logarithmic graph, cumulative percentage against equivalent particle size diameter, from which the proportion of material in the various size fractions was obtained and reported in tabular form.

One drawback encountered in this method was the paucity of information received for the fine sand fraction, resulting in a poorer curve and less accurate estimation of the percentage of sediment in this sector. To improve on this, a slight variation was introduced involving sieving of the fine sand fraction. After wet sieving of a prepared sample through a 0.064 mm mesh, the material retained was dried and placed in a sieve nest with meshes of 2 mm, 1 mm, 0.5 mm, 0.25 mm and 0.125 mm. The nest was shaken for 15 minutes on an automatic shaker and the weight of material retained on each sieve finally recorded. In conjunction with this, the sediments which had passed through the original 0.064 mm mesh were subjected to normal hydrometer analysis.

From this second method it was possible to plot an increased number of points on the graph and in consequence a more accurate curve was produced.

All samples were analysed for particle-size composition. A number of checks were made in the usual way by running duplicate experiments with the same sample and the two methods used were compared in a similar fashion. As with other results the figures from particle-size analysis will be discussed where relevant in the following chapters.

Heavy mineral analysis. A natural consequence of particle-size analysis was the separation of the fine sand from the other fractions. This is most suitable for heavy mineral analysis since the fine sand has the broadest and most representative range of minerals. By a combination of flotation in bromoform, centrifuging and filtering, the heavy minerals (Specific Gravity 2.90) were separated from the light and slides of the former were prepared. These slides were examined under a polarising microscope, individual minerals being identified by resort to reference books and by comparison with specimen slides. In each case over 100 grains were counted and the results recorded as a percentage of the total.

Although the samples examined for heavy mineral composition were only a small proportion of the total, an attempt was made to choose those which appeared most representative. The numbers involved are probably too small for definite interpretations to be made from those results alone, but when viewed in conjunction with other factors such as field observations and mechanical analysis they throw a certain amount of light on the geological derivation of the sub-carse deposits.

The pages that follow contain the interpretations put upon the results obtained from the methods described above. Some are less important, others, such as the borehole logs, are obviously fundamental, but used together and in conjunction with careful observation in the field, they make it possible to describe and explain the landscape which lies beneath the carselands of the northern side of the River Forth.

CHAPTER III

THE STRATIGRAPHY AND SUB-CARSE MORPHOLOGY OF THE AREA BETWEEN THE MENTEITH MORAINE AND BLAIRDRUMMOND

The area with which this study is concerned is remarkably homogeneous. Apart from the Menteith Moraine, rising above the western carselands and the odd eminences protruding through the clay in the vicinity of the Stirling gap, it consists essentially of a long relatively narrow subdued plain, its regular surface broken by deep ditches, the remnants of the once extensive peat mosses and, beyond Stirling, by the scattered spoil-tips of coal mines. Along the southern margin flows the River Forth, its course incised in the clay, separating this northern portion of the carse from a similar area on the opposite side of the valley. Two major rivers, the Teith and the Devon, and two streams, the Goodie Water and the Allan Water, joining the Forth on its left bank, add a certain variety to the region, but all in all it is characterised by a considerable degree of monotony.

This is especially true from a morphological viewpoint and for descriptive purposes the carselands can be considered as a single unit. However, the present investigation is chiefly concerned with the deposits lying beneath the carse. When these are considered it can be shown that the area is divisible into three parts, two of which are essentially similar, but separated from each other by a unit which is geomorphologically very different from either. Taking points on the carse surface beneath which these units lie, they can be listed as follows:- the area between the Menteith Moraine and Blairdrummond, that between Blairdrummond and the Stirling gap and finally the remainder stretching from the Stirling gap to Kincardine-on-Forth and including the Devon valley. In the following pages these will be considered in turn, firstly in terms of their stratigraphy and secondly with reference to their morphology as it must have appeared prior to the deposition of the carse-clay.

The Menteith Moraine to Blairdrummond*

As already indicated in a previous chapter, the Menteith Moraine comprises a complex series of mounds formed largely of fluvioglacial debris and glacially transported marine clays. Associated with the moraine are sheets of outwash that slope eastwards to pass beneath the carse-clay and related deposits. North of the Forth, the main mass of fluvioglacial gravel spreads out from a gap cut in the moraine by meltwaters and presently utilised by the Goodie Water. In this area, the course of the Goodie is an artificial cut and for a distance of almost 400 m the gravel can be followed eastwards as an exposure in the banks of the stream. Eventually, the gradual decline of the surface of the outwash carries it beneath the bed of the stream and further investigation is only possible after boring through the overlying deposits (Fig.III.2).

Some 400-500 m south of the Goodie Water, the carse shoreline trends roughly east-west and here the relationship between the outwash gravel and adjacent deposits is again apparent. Deep drainage

*Figure III.1 is applicable to this entire section.

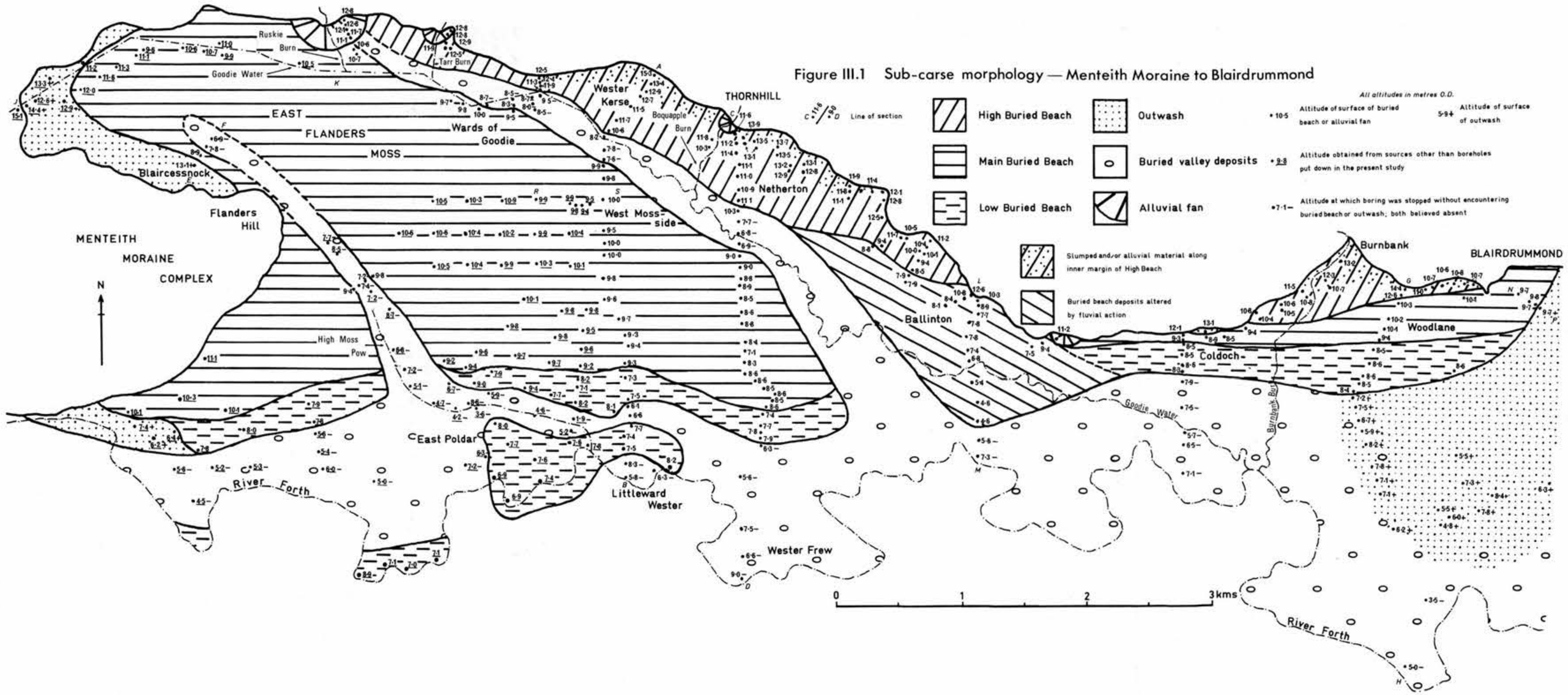


Figure III.1 Sub-carse morphology — Menteith Moraine to Blairdrummond ditches, cut to permit the afforestation of this area, have produced numerous exposures and from the slopes below Blaircessnock Farm, the gravel can be followed beneath the peat of Flanders Moss, which extends beyond the limits of the carse at this point. At about 100 m from the edge of the moss, the gravel passes below the carse-clay (Fig.III.3) and near the same point its surface falls below the base of the main ditches. Beyond this the presence of gravel was demonstrated by hand boring for some 200 m in a north-easterly direction before it disappeared or lay at depths which could not be reached with the equipment available.

The ditches in this area provide numerous exposures that show the gravel to be quite typical of outwash. The deposits are roughly stratified, consisting mainly of medium to large gravel but with coarse sand and finer gravel in places. The change from one size to the other is often quite sharp both vertically and horizontally, indicating rapid changes in channel position during the formation of the outwash plain. The well-rounded nature of individual stones is also representative of this mode of formation.

The greater proportion of the rocks that make up the outwash are Highland in origin, carried out of the hills behind Aberfoyle by the ice that produced the Menteith Moraine. Palaeozoic sedimentaries of Old Red Sandstone age form the bedrock of the area adjacent to the moraine, but the boundary with the Highland metamorphic rocks lies only a few kilometres to the west. Although no precise count was taken, the limited number of Old Red Sandstone fragments in the gravel was apparent in this particular area. The presence of a layer of marine clays immediately above the Old Red sediments appears to have been sufficient to limit the erosion of the latter, thus limiting its inclusion in this part of the moraine and consequently in the outwash. Towards the hills that back the carse, a higher proportion of Old Red Sandstone sediments in the gravel might be explained by deposition from streams flowing off these hills.

Quartzites, grits and schists are probably the most common rock-types present, corresponding to the petrology of the Highland Border in the vicinity of Ben Lomond and Ben Venue. The latter, according to Geological Survey maps, is composed of schistose grit, but also has a band of epidote-chlorite-schist associated with it. Green chlorite-schist is common in the outwash gravel and it seems probable that it originated in the neighbourhood of Ben Venue. This is the only rock type which can be related to a specific source by simple inspection. Detailed geological examination could undoubtedly improve on this, but for present purposes this is not necessary. The chlorite-schist is mentioned here, because it is distinctive, acting as an indicator, and in addition has further implications when certain of the sub-carse deposits are examined.

Measurements on the outwash, recorded by Sissons (1966) in the vicinity of the Goodie Water, show that it slopes from 23.5 m, at its western end, down to 10.1 m some 3 km farther east (Fig.III.2). Over this distance there is a gradual decrease in gradient until the surface is at a height of 10.1 m, where a sharp increase takes place. South of the Goodie, the same eastward slope is observable, but over a much shorter distance (Fig.III.3). Below Flanders Hill the gravel passes beneath the surface peat at a height of 14.9 m O.D. and slopes in a direction between east and north-east. The slope is rather great and at distances beyond 200 m from the edge of the moss the gravel cannot be located. Borehole 666 shows the outwash lying at 13.1 m O.D. while at a point 100 m to the east it is encountered at 8.2 m. Beyond this, boreholes were put down to 7.8 m O.D. and 6.9 m O.D. but the gravel could not be located. The gradient of the outwash surface in this second case is obviously much greater than in the first and requires some explanation. However, this is best done after consideration of certain other elements of the morphology of the area as a whole.

It has been pointed out above that eastwards from the moraine the outwash passes beneath surface peat and carse-clay. In fact, these are only the upper elements of a more complicated stratigraphy. Beneath the carse lies a bed of buried peat resting on the grey silty sand of a buried raised beach. The sloping gravel eventually passes beneath these also, so that immediately east of the moraine, the following elements can be taken as representative of the stratigraphy:

5. Surface peat.
4. Carse-clay.
3. Buried peat.
2. Grey silty sand.
1. Gravel.

The grey silty sand of this section corresponds to one of three buried steps recognised in this area by Sissons (1966) and distinguished by altitude as well as characteristic colour and composition of their constituents. Despite the differences, there are certain similarities that suggest a common origin. All are composed of fine water laid sediments with a remarkable uniformity of composition over large areas. All are relatively flat or gently inclined and occupy a position that at the time of formation would have been at or near the head of an estuary. Taken together, these facts suggest a marine origin, which has been proved by pollen analysis (Newey, 1966) for the two lower steps. It appears unlikely that the highest step had a completely different origin and all three have been called "buried raised beaches", due to their position beneath the carse but above present sea-level. (As already noted, the term "buried raised beach" will be used for deposits of both marine and estuarine origin lying beneath the carse, no distinction being drawn between the two.)

The three buried raised beaches discovered by Sissons on the south side of the Forth in this area seem to be present on the north side, occupying essentially similar positions with respect to each other but with certain significant differences. For convenience at this stage the buried beaches in the northern area have been provisionally equated with the southern features and will be referred to by Sissons' terms. This point is fully discussed and justified below (Chapter VII).

The highest buried beach is found in the northwestern part of the area under investigation. It forms a continuous feature extending for almost 5 km in an east-west direction with a width varying between 150 m and 750 m. At its inner or northern margin, where it ends against the steeply rising ground that also marks the inner edge of carselands, its height varies between 12.9-12.5 m O.D. in the west and 11.7-10.4 m O.D. at its eastern end. In general, there is also a slight slope outwards from the back of the beach, where the average height is 11.9 m compared with 9.5 m at the front. At Netherton Farm near Thornhill, however, the figures for back and front are 11.6 and 11.1 m respectively. For the most part, the surface of the beach is remarkably uniform except towards the backslope where the normal smooth profile is broken by hummocky deposits of coarse sand which appear to have slipped from the backslope while the beach was forming or after it had formed (Figs.III.4 and III.5).

The buried beach is covered by a layer of peat, varying in thickness from a few centimetres to half a metre at a maximum. East of Thornhill the peat is usually absent and the carse rests immediately upon the beach itself. The sediments of the beach are for the most part pink or purple-pink, except in the topmost 5-10 cm where there is a characteristic greyish coloration that exists irrespective of the presence or absence of overlying peat. Along the northern margin, the colour is often more brown than pink.

The variation in colour is parallelled to a certain extent by a variation in composition. There is little difference between the grey and pink sediments which are essentially fine grained with varying proportions of sand, silt and clay. However, the brownish-pink sediments are of a coarser texture, perhaps due to their proximity to the former shoreline. Coarser sediments are also associated with the burns that flow on to the carse from the higher land to the north. The Boquhapple, Tarr and Ruskie Burns appear to have been in existence and depositing sand and gravel into the sea at the time of formation of the pink beach, for in the vicinity of these streams, the beach sediments are usually coarser than in other areas. The logs for boreholes 634, 636 and 638 indicate this.

The Ruskie Burn has produced an alluvial fan which is now

THE SUPERFICIAL DEPOSITS OF THE AREA BETWEEN –
— THE MENTEITH MORAINE AND BLAIRDRUMMOND

(The location of each section is indicated in Figure III.1.)

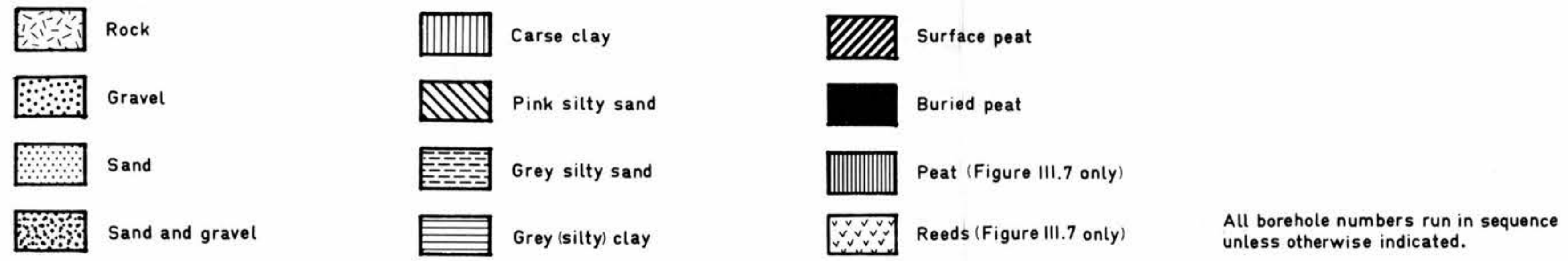


Figure III.4 Wester Kerse – Littleward Wester

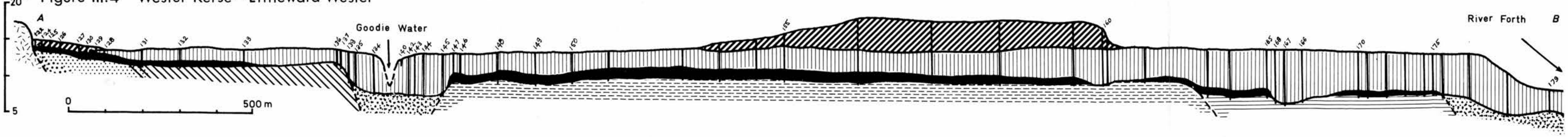


Figure III.5 Netherton – Wester Frew

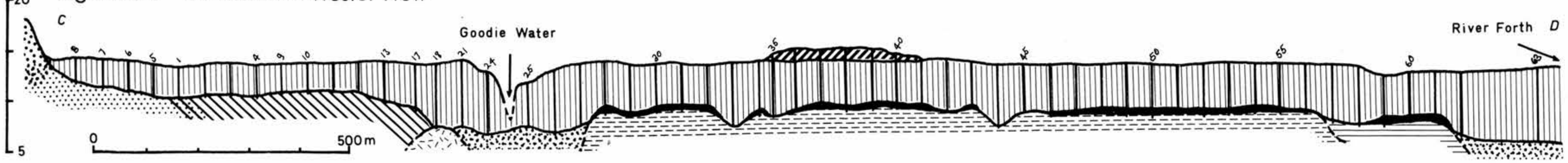


Figure III.3 Blaircessnock

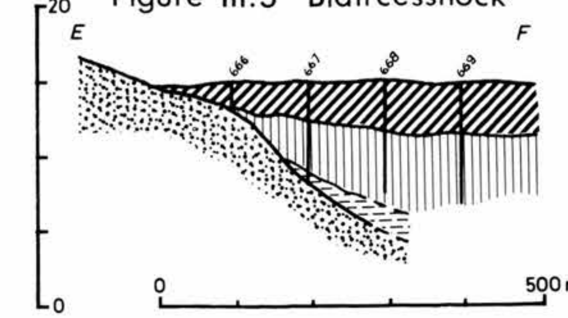


Figure III.6 Woodlane

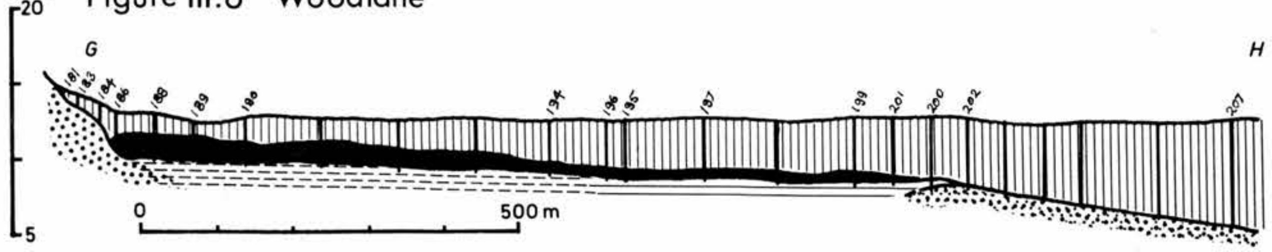
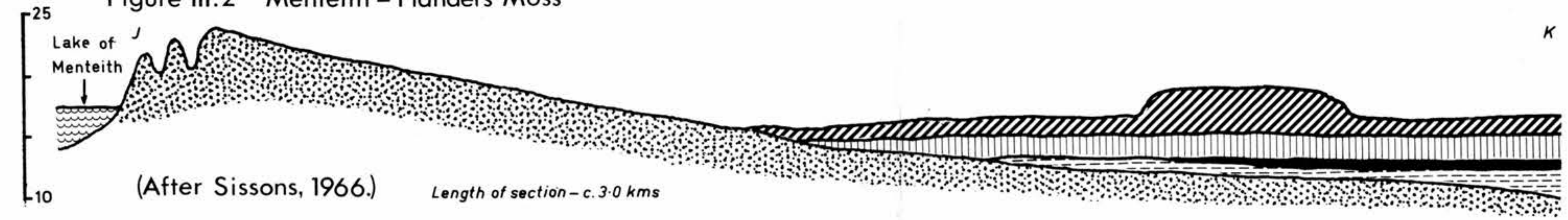


Figure III.2 Menteith – Flanders Moss



(After Sissons, 1966.)

Figure III.8 Ballinton

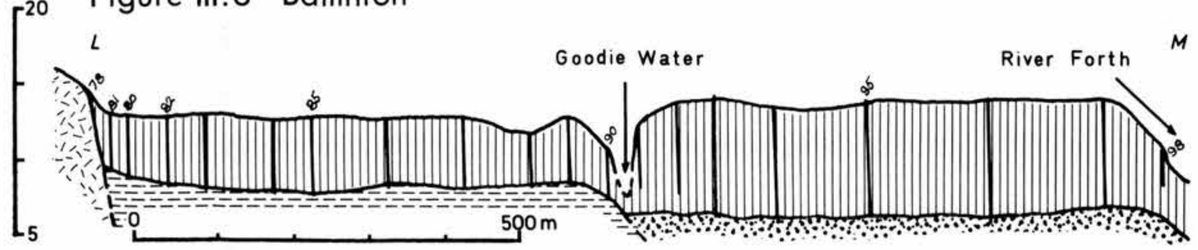


Figure III.9 Blairdrummond

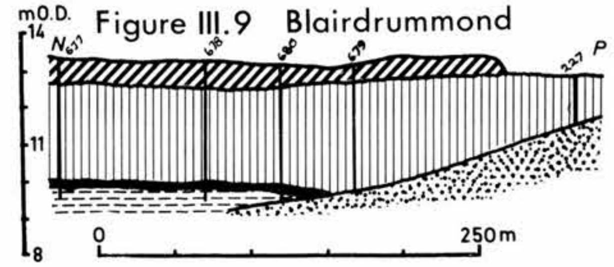
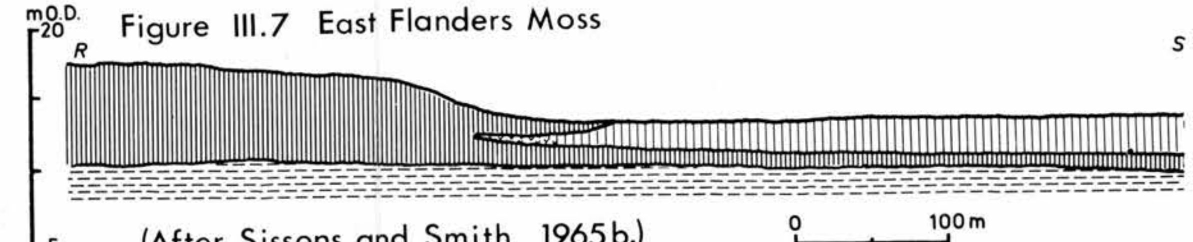


Figure III.7 East Flanders Moss



(After Sissons and Smith, 1965b.)

buried beneath the carse. It can be followed for at least 300 m from the back of the carse and is composed of grey-brown fine sand for the most part with some clay in places. At first sight this bears little relationship to the pink deposits of the highest beach, but the latter appears to be represented by the presence of pink silty sand mixed with the fine grey-brown sand of the fan. One borehole (657) shows pink clay lying between the carse-clay and the grey-brown sand of the fan, at a height of 12.9 m O.D. This is the most westerly point at which the presence of the High Buried Beach has been indicated. Beyond the Ruskie fan, the boreholes are rather limited in number and position, but no evidence of the pink beach has been found there. If it is present, it can only be of very limited extent.

Traced southwards, the High Buried Raised Beach ends abruptly along most of its length. It is delimited sharply by a valley, also buried by the carse and more or less following the present course of the Goodie Water. The only exception to this occurs at the eastern end of the beach where, over a distance of less than a kilometre it lies adjacent to a subdued area of fine grey sand, the junction being marked by a slight rise half a metre high.

The buried valley can be traced for a distance of over 5 km in a south-easterly direction from a point near Wards of Goodie. It is only one of a number of valleys that lie beneath the carse in this area and they are best considered as a group. They will be described in some detail below, but at present an examination of the sediments lying to the south of the valley is more pertinent.

These sediments are a distinct element in the stratigraphy over a large part of the area under study. They consist essentially of grey silty sand with remarkable overall uniformity and belong to the Main Buried Raised Beach as designated by Sissons (1966). As noted above, the deposit is encountered immediately east of the Menteith Moraine overlying fluvioglacial gravel. From here, it can be traced for 11.0 km eastwards as far as Blairdrummond, with only one break where it is cut by a buried valley. Its maximum extent in a north-south direction is about 2.0 km.

The grey silty sand forms a surface that is almost flat, with only a gentle slope to the east. Near the moraine it is encountered at heights between 12.0 m and 11.1 m O.D. Although the exact position of the shoreline of the beach is not apparent, due to the presence of the buried valley along its northern edge, there is a slight slope to the south, representing the normal beach slope (Figs.III.4, III.5 and III.6). Heights of 10.1, 9.9 and 9.4 m O.D. along the back or northern margin correspond to figures of 9.2, 8.7 and 8.2 at the front of the feature.

The beach is composed almost entirely of fine grey or grey-green sand with considerable proportions of silt and clay. It also contains an abundance of micaceous fragments which impart a characteristic sheen to the sediments. It is thought that the green coloration and the mica may have originated in the breakdown of rock such as the chlorite-schist already remarked on as occurring in the Menteith outwash. The fine sand and silt fractions normally form the greater part of any sample and the term "silty sand" can be used to describe the deposit (Sissons and Smith, 1965b). In places, the upper few centimetres of the deposit have a high percentage of clay and here the term "silty clay" has been used. Such a situation is especially common between Coldoch and Blairdrummond, although by no means confined to that area.

The thickness of these deposits is not accurately known since the equipment used would not penetrate more than 50-100 cm into them and no commercial borehole records are available. In some cases this amount of penetration was sufficient to reach the underlying deposits (Boreholes 200 and 201 or 4/DES and 6/DES) but undoubtedly the thicknesses recorded are not representative, due to the thinning of the beach deposits in the vicinity of the Blairdrummond and Menteith gravels. The greatest thickness is recorded in borehole 653, put down in the bed of the Goodie Water, where 2.0 m of grey silty sand overlie coarse grey and pink sand. Complete penetration was also possible in a stretch along the back of the carse between East Coldoch and Burnbank. The grey silty sand varies in thickness between 9 cm and 34 cm and rests upon pink silty sand in a number of boreholes. (693, 695, 696 and 707.) Although the surface of the pink deposit varies in height between 10.8 and 8.3 m O.D., it may well represent the High Beach in this area, the height variations being produced by a combination of the Burnbank Burn and a small stream passing on to the carse near Coldoch House. This being so, the difference in height between the sea-level that produced the Main Beach and the surface of the High Beach must have been sufficient only for the deposition of a thin veneer of grey silty sand. Again this is a special case and with this limited amount of information, no accurate assessment of the general thickness of the Main Beach deposits can be made.

Almost everywhere the Main Buried Beach is covered by a layer of peat, sandwiched between it and the overlying carse. The peat varies in thickness from a few centimetres to over a metre, but commonly measures 10-20 cm. The greater thicknesses are found beneath East Flanders Moss and would appear to be associated with a gradual thinning of the carse. Near Thornhill, the average thickness of the carse above the Main Beach is 4.1 m while at West Moss-side, less than a kilometre to the west, it is only 2.9 m. Within a few hundred metres still farther west, the carse-clay is no longer encountered and the peat lying on the Main Buried Beach is continuous with the surface peat of Flanders Moss. This situation is found in a roughly circular area, noted by Sissons and Smith (1965b) and explained by them as indicating the position of a peat bog that was able to maintain itself within the encroaching carse-sea (Chapter 1). Here the peat has a depth in excess of 7.0 m, resting directly upon the grey silty sand of the Main Buried Beach. Technically this is the greatest thickness of peat above the deposits of the Main Beach, but it is obviously atypical and the figures already quoted are most common.

In many boreholes a transition zone is found to occur at both the upper and lower limits of the buried peat, showing the continuity of the progression from buried beach, to peat and eventually carse-clay. Five or ten centimetres of transitional deposits, consisting of peat mixed with clay or grey silty sand are not unusual but often the zone of mixing is too small to merit inclusion in the borehole logs.

Within the peat layer itself, woody material is often present. No distinct pattern is visible as far as vertical distribution is concerned. Sometimes the wood is found in the top of the peat layer, sometimes in the bottom, occasionally it replaces the buried peat completely and frequently no wood is present at all. In a horizontal direction, the wood appears to follow some pattern, for it is more common in some areas than in others, suggesting a patchy distribution of the original trees. There is also considerable variation in the type of wood encountered. The presence of smooth, slightly silvery bark can be used to recognise birch, the wood of which is soft and light yellow in colour. Fragments recovered in the borer also included pieces of soft red, and hard dark brown or black wood, which local inhabitants claimed to recognise as pine and oak respectively. Other, non-arboreal, vegetable matter is also recognisable in the buried peat in places, including stems of *Juncus* and *Phragmites*, as well as the shiny red seeds of *Menyanthes trifoliata*. Undoubtedly, the distribution of these fragments is of some significance, as Newey (1966) has shown, and would merit further investigation by botanists and palynologists, but in the present study, the limited number of samples taken within the peat layer and limited botanical knowledge meant that the variety of vegetable matter could be no more than noted.

In an area, 2.0 km south-east of Thornhill, the grey silty sand is not covered by peat (Fig.III.8). Here also the deposit is at a much lower level than is normal for the Main Beach in this area. North of the Goodie Water, heights range from 7.8 m O.D. to 7.3 m O.D., which are at least 1.0-2.0 m lower than might be expected from comparison with adjacent areas. Despite the similarities in colour and composition between the sediments of this area and those of the Main Buried Beach, the height difference raises problems. However, the variation may be associated with a change in position of the buried valley of the Goodie Water.

At its southern edge, the step that forms the Main Buried Beach descends through a height of 0.5 to 1.5 m below which the lowest buried beach is reached. This is the smallest of the three beaches first recognised by Sissons (1966) and is best developed west of the Goodie Water. It is widest in an isolated island beneath the carse in the vicinity of East Poldar Farm, where it attains a north-south width of almost 500 m (Fig.III.4). In most areas it exists as a narrow strip, no more than 150-200 m wide. West of the Goodie Water, it occupies a position on the southern margin of the Main Buried Beach and is continuous for a distance of nearly 5 km in an east-west direction, with only a short break in the vicinity of High Moss Pow.

Of the 35 heights obtained on the surface of this Low buried beach, only four lie outwith the range 8.2-7.3 m O.D. There is no apparent pattern to the distribution of the heights, although the lowest heights within the range given are found towards the eastern end. However, this may be related to the greater number of boreholes put down in that particular area. Again there is no slope towards the front of the beach as was found in the two previous cases, although on the isolated mass mentioned above, the heights tend to be greater along the northern margin than on the southern.

In colour and composition, the Low Beach is somewhat similar to the Main Beach. It is grey or greenish-grey in colour and consists of sticky silt and clay in the top 30 or more centimetres. Beyond this, the deposit becomes gradually more sandy by the inclusion of thin layers of fine grey sand until it resembles the sediments of the Main Buried Beach. On the latter, however, the cover of silty clay is not usually so thick nor is it so extensive. Like the Main Beach, this lowest feature contains a considerable proportion of fine micaeous particles.

The grey silty clay of the Low Beach usually contains numerous stems of reeds that merge upward into the overlying peat. This peat is as much as 40-50 cm thick and is often difficult to penetrate, due to its compressed nature, as well as the high proportion of wood it contains. Lying as it does, beneath more than 5.0 m of carse-clay in most cases, compression has been intense; so intense, in fact, that tree branches obtained from the peat layer, where it is exposed in the banks of the River Forth, can be oval in cross-section due to the pressure from above. As a result, the peat layer is very tough and in some cases penetration was impossible. Where this was so, the thickness of the peat and therefore the height of the Low Beach has been estimated from the average figures recorded in the surrounding area. This may involve some degree of error, but it seems unlikely to be more than 10-20 cm.

The deposits of the Low Buried Raised Beach and the peat associated with it are exposed in the banks of the Forth at a number of points, mainly in the western part of the area. In most places, however, approaching the Forth the Low Beach disappears, the carse becomes thicker and layers of sand alternate with the lower layers of the clay. Marine shells and shell fragments are also found in these lower layers. From work carried out in this area and on the south side of the Forth, it is apparent that there is a belt, varying in width from half a kilometre to a kilometre and following the general trend of the meander zone of the Forth, in which neither the buried peat nor the buried beach deposits are present. This belt is taken to indicate a buried valley that operated as an estuary at different times in the past.

As already indicated, there are a number of buried valleys beneath the carse in this area. That of the River Forth is the major one, but there are also valleys beneath the Goodie Water and High Moss Pow that can be thought of as tributary to the main buried valley. In addition, there are also buried valleys or gullies cut into the surface of the buried beaches. These are normally very limited in both depth and width but are quite numerous in places as can be seen in the Netherton-Wester Frew section (Fig.III.5). They are most commonly found in the Main Buried Beach, seldom more than a metre in depth and containing none of the buried peat that normally covers the surface of the beach. Samples from the bottoms of these valleys give sediments little different from the normal grey silty sand of the beach, suggesting that they are products of erosion rather than areas of non-deposition of beach sediments. The absence of peat within the gullies can be explained by the presence of flowing water when the peat blanket was growing.

These gullies appear to have acted as tidal creeks as the carse-sea rose, for shell beds may be found within them (e.g. Boreholes 42, 44 and 45). The shells are often very well preserved, both valves being intact in some cases, and it is relatively easy to identify different genera. *Cardium* is probably the most common shell encountered, but *Mytilus* and *Ostrea* are also found in considerable quantities.

In contrast to these relatively small gullies, the main buried valleys are rather impressive features. As already pointed out, the valley beneath the Goodie can be traced for a distance of over 5.0 km, while the High Moss Pow valley at about 3.0 km is slightly shorter. It is probable that the small valleys drained into these main ones, the latter in turn joining with the larger buried estuary of the Forth.

For most of its length, the buried valley of the Goodie Water follows the course of the present stream and its junction with the main buried valley lies close to the confluence of the present stream with the Forth. A few hundred metres west of Wards of Goodie, the two features -- stream course and buried valley -- diverge, the latter continuing in a north-westerly direction while the former trends roughly east-west. From that point westwards, peat and grey silty sand can be located in or beneath the bed of the stream whereas downstream neither is encountered. From that point also, the buried valley begins to peter out and a few hundred metres to the north-west it is replaced by the coarse grey-brown sand of the Ruskie fan. Water from the Ruskie Burn probably flowed into the pre-carse Goodie Water helping to produce and maintain the buried valley.

The heights obtained within the buried valley show a considerable range from section to section, being greatest in the north-west and least in the south-east near the junction with the valley of the Forth. Taking average figures, there is a reduction in height downvalley from 8.7 m O.D. at Wards of Goodie, through 7.7 m at Netherton Bridge, to 4.9 m O.D. at Bridge of Goodie. Because of the limited penetration possible with the Hiller borer in coarse sediments, these heights may not be representative of the valley floor. However, the heights quoted indicate points at which the deposits are increasingly difficult to penetrate and, bearing in mind the method of boring, the points should be related to each other. This is borne out by the coarse nature of the sediments in the valley. Thus, although the slope indicated need not refer to the valley floor, it does appear to be applicable to sediments lying upon this floor.

In several boreholes (18, 19, 20, 23, 645 and 648) it is possible that rockhead was reached. Due to the limitations of the equipment used and the absence of commercial boreholes, this could not be proved conclusively, but there is reason to believe that rock was encountered. In the boreholes mentioned the presence of a solid object was indicated by a dull "ring" transmitted up the shaft of the borer. This sometimes happens if the end of the borer hits an individual stone in a mass of gravel. However, in that case it is often possible to displace the stone and work the boring screw into the gravel, after which the instrument usually jams. With big gravel containing large cobbles this might not be possible, individual stones being too large to displace. In an attempt to discover whether or not this was so, three boreholes (18, 19 and 20) were put down, 5.0 m apart, in a triangular pattern. In each case, after the dull "ring" of the borer striking, no further penetration could be achieved and the maximum height difference on the rock or gravel surface was only 3.0 cm. It is possible that in each hole the borer came down against a large piece of gravel but this seems unlikely and when a similar situation was discovered only 10.0 m from borehole 20, it was considered probable that rockhead had been reached. Thus, the picture of the buried valley of the Goodie Water is of a valley 150.0-400.0 m wide with fairly steep sides, lying some 2.0-4.0 m below the level of the adjacent buried beaches, its floor covered by coarse sand and gravel through which solid rock occasionally protrudes, and sloping in a south-easterly direction towards the main valley of the Forth.

Much less is known about the buried valley that lies beneath High Moss Pow. This is due mainly to its relative inaccessibility, reaching as it does, well into East Flanders Moss. However, near its south-eastern end, the moss has been cleared from the carse surface and the buried valley can be located more easily there. It is represented at the surface by a shallow depression through which the Pow flows. Followed back on to the Moss the depression persists, becoming narrower upstream. The limited number of boreholes that have been put down through the surface peat indicate the absence of buried peat or buried beach deposits but establish the existence of coarse sand and gravel alternating with the carse-clay in its lower layers or lying beneath it (Boreholes 373/JBS-377/JBS). At the same time two lines, of four boreholes each, at right angles to the general trend of the valley show that the grey silty sand of the Main Beach lies to either side of it (Boreholes 630-633 and 666-669).

The buried valley of High Moss Pow is on a smaller scale than that of the Goodie Water, at least in terms of length, being almost 2.0 km shorter. It is at least 100.0 m wide one kilometre upstream from its junction with the Forth and appears to widen towards the main valley. Heights within the valley vary from more than 7.0 m O.D. near its head to 5.2 m O.D. near its mouth, with a variety of values at intermediate locations. The exact upstream limit of the valley has not been located, but it appears to fade out a few hundred metres north-west of Flanders Hill, where a continuous cover of grey silty sand is found. Thus, despite the limited amount of information available, a buried valley can be seen to exist beneath High Moss Pow and indeed the very existence of the present stream may well be due to the presence of that valley.

Both of the valleys described join up with the main buried valley of the River Forth which can be followed to Stirling and perhaps beyond. In the area west of Stirling, there are few commercial boreholes and the altitudinal information obtained normally refers to levels beyond which it is not possible to penetrate with the Hiller borer. Those boreholes that have been put down between Menteith and Blairdrummond show great thicknesses of superficial deposits: thus on the south side of the Forth, rockhead was ultimately reached at 99.4, 38.9 and 14.6 m below Ordnance Datum. Similarly, at Bridge of Frew, on the Forth, figures of -18.0, -4.1 and -3.3 m O.D. have been obtained. In contrast, using the Hiller, rockhead could not be located, the lowest altitude reached being 1.9 m O.D., where boring was stopped by gravel. The greatest proportion of heights lies between 5.0 and 7.0 m O.D., sufficiently far below the level of the buried beach deposits to preclude their presence but undoubtedly, in most cases, still far from rockhead.

Along its northern margin, the buried valley of the Forth is relatively sharply defined, the changeover from beach to valley taking place in a horizontal distance of as little as 10.0-25.0 m. Such definition is common in the western part of the area, but in the east the margin of the buried valley is not so sharp. In the vicinity of Blairdrummond, coarse sand and gravel carried out on to the lowland by the River Teith has been deposited in the buried valley of the Forth and it is difficult, if not impossible, to decide where the Teith sands and gravels end and those of the Forth begin. In places, shell fragments enable a distinction to be made (Boreholes 216 and 218) but these are the exception rather than the rule.

The morphological units first encountered immediately east of the Menteith Moraine are limited in their eastward extension by the sands and gravels associated with the River Teith (Fig.III.9). Not only do these deposits interfere with the buried valley of the Forth but they also limit the buried beaches in this area. The sediments of the Main Buried Raised Beach can be followed eastwards almost as far as Blairdrummond, where they overlie the alluvial fan of the Burnbank Burn and eventually die out against the rising sand and gravel of the Teith system (Boreholes 227, 677, 678, 679 and 680) in much the same way as they do in the west against the Menteith outwash. Thus, at Blairdrummond, a sharp morphological boundary occurs and this has been utilised for purposes of description.

Conclusion

The carselands on the north side of the River Forth between the Menteith Moraine and Blairdrummond mask a variety of morphological elements that can be summarised as follows:-

1. The Menteith outwash plain sloping from a height of 23.5 m O.D. near the moraine to pass beneath the carse-clay and its peat cover at about 15.0 m O.D. to reach a low of 10.1 m, 3.0 km farther east.

2. The High Buried Raised Beach, lying beneath the northern limits of the carse, at heights mostly between 10.0 and 12.0 m O.D. and composed of pink silty sand for the most part.

3. The Main Buried Raised Beach, the most extensive of the buried beaches, overlapping onto the outwash plain at a height of about 11.0 m O.D. and sloping gently eastwards to an average height of 9.0 m O.D. near its eastern end. The sediments of the beach are grey in colour and of the texture of silty sand. A bed of peat is normal on the surface of this feature.

4. The Low Buried Raised Beach, lying along the southern fringe of the Main Beach, west of the Goodie Water, at heights between 7.0 and 8.0 m O.D., the least extensive of the three beaches. Grey in colour, it varies in composition from silty clay at the surface to silty sand at depth. Like the Main Beach, it commonly has a peat cover.

5. The buried valley of the River Forth, along with those of its tributaries, the Goodie Water and the High Moss Pow, diversifying the sub-carse morphology and producing belts of mixed sediments that contrast sharply with the uniformity of the beach deposits.

CHAPTER IV

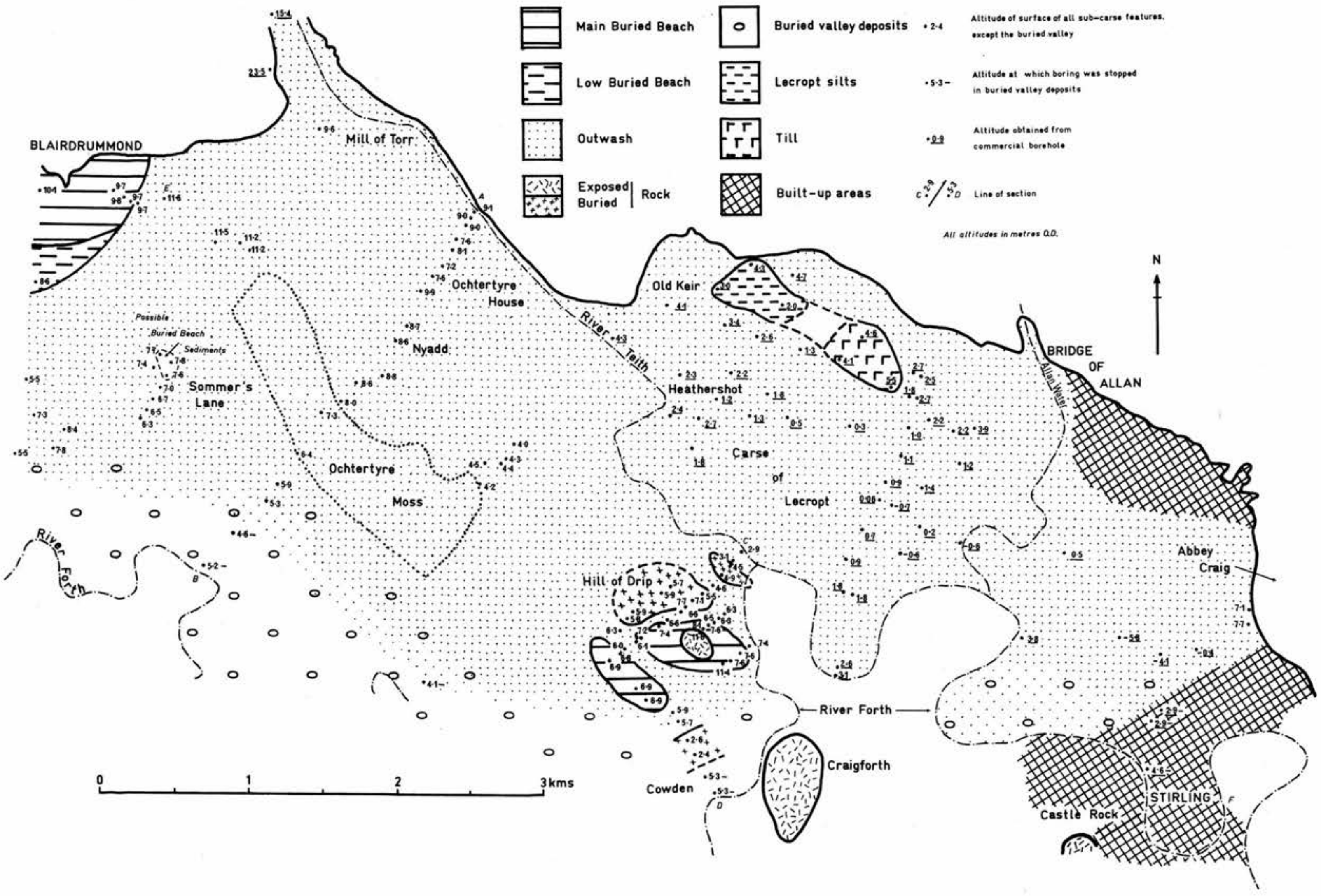
THE STRATIGRAPHY AND SUB-CARSE MORPHOLOGY OF THE AREA BETWEEN BLAIRDRUMMOND AND THE STIRLING GAP*

The carse between Blairdrummond and Stirling takes the form of a subdued clay plain similar in many ways to that already described in the west. From the narrows at Coldoch, it widens to a maximum of almost 5 km in the vicinity of Ochtertyre, only to be limited again at the Stirling gap. On the south it is bounded by the meandering River Forth and near Blairdrummond House the River Teith enters the carse, occupying a shallow valley and flowing in a south-easterly direction until it joins the Forth slightly more than a kilometre west of Stirling. The Allan Water, also slightly incised, meets the Forth nearer the town. To the north the land rises away from the former carse shoreline, often quite sharply, as is the case between the Mill of Tor and Ochtertyre House, where the Teith has helped to produce steep bluffs more than 15 m high and near Bridge of Allan, where the western end of the Ochil Hills is encountered.

Several eminences that must have been islands in the carse sea now protrude through the clay, adding some variety to the landscape. There are three in all, the Nyadd and Hill of Drip composed of Old Red Sandstone and Craigforth of igneous origin, possibly

*Figure IV.1 is applicable to this entire chapter.

Figure IV.2 Sub-carse morphology — Blairdrummond to Stirling



intruded into crustal weaknesses associated with the Ochil Fault which passes between it and the Hill of Drip. The first two stand only a few metres above the general level of the carse compared with the more resistant intrusives of Craigforth rising 60 m above the plain, but it has been suggested (Dinham, 1927) that in "pre-glacial" times all three formed part of the watershed between the glens of the Forth and the Teith. In this area, however, glacial erosion has been significant (Chapter I) and unless it becomes possible to reproduce the "pre-glacial" landscape with some accuracy, Dinham's suggestion must remain unsubstantiated. At Stirling the already narrow plain is further restricted by the presence of Abbey Craig and the Castle Rock in the gap and here the Forth swings towards the northern margin of the carse, limiting its width to a few hundred metres in places while providing a natural eastern limit to the area.

Although the carse east of Blairdrummond is essentially similar to that farther west, there are several important variations. To the observer, the carse at Blairdrummond, Ochtertyre or Lecropt is obviously drier than that at Thornhill and this is accompanied by a greater thickness of the carse crust in the first three areas. No accurate measurements were taken but field observation showed that in the vicinity of Thornhill, the crust is normally less than a metre thick, while to the east it commonly exceeds this figure. Where a thicker, tougher carse crust is accompanied by a general toughening of the carse-clay, penetration becomes very difficult if simple handboring techniques are used. Indeed, in the Carse of Lecropt it proved impossible to reach the sub-carse deposits in all but a few cases, due to the impenetrability of the carse-clays. In this area, however, numerous commercial boreholes were available for consultation.

The thicker crust and generally increased toughness of the clay between Blairdrummond and Stirling appears to be associated with the drier conditions produced by improved drainage. In well drained arable land or close to ditches and streams the crust increases in thickness whereas in poorly drained areas, near the remnants of the once extensive peat mosses, for example, the crust is very thin or even non-existent. In turn, the variations in drainage are related to several factors that include history, morphology and stratigraphy.

In common with most of the carselands west of Stirling, the area at present under consideration was once covered with a blanket of peat moss. Early agriculturalists undoubtedly removed some of this cover, particularly around the edges where it was relatively thin, but it was during the late eighteenth century and into the first half of the nineteenth that the great clearances took place, the peat being removed to expose the potentially rich clay beneath. The efforts of the improvers were such that in the 25 sq km of carseland on the north side of the Forth between Blairdrummond and Stirling only the relatively small moss at Ochtertyre remains, covering an area of slightly more than a square kilometre. At the same time numerous deep ditches were cut across the area to carry off excess water to the Forth or Teith and in the century since the improvements this part of the carse must have dried out considerably helping to produce the thick crust and tenacious clay encountered today. On the other hand, to the west, in the Thornhill area, the moss clearances were less extensive and some 12 sq km of peat remain in Flanders Moss acting as a natural reservoir and helping to prevent the carse from drying out in the same way as it has to the east. Thus, it would seem that historical factors are partly responsible for variations in the carse east and west of Blairdrummond.

The presence of the River Teith no doubt also helps natural drainage. West of Blairdrummond a depression is often encountered along the back edge of the carse and this allows excess moisture to collect, encouraging the persistence of a peat cover. Near Ochtertyre, the Teith aids drainage as it flows for 3.0 km along the northern edge of the carse in a flood-plain that lies below the general surface level. The driest part of the area is the Carse of Lecropt, bordered on three sides by the Teith, Forth and Allan Water and this is reflected in the consistency of the carse-clays. It can also be noted that the wettest area is that midway between the Forth and Teith in a location that must have been difficult to improve during the clearances for it is now occupied by the remains of Ochtertyre Moss.

A final factor that appears to affect the toughness of the carse in this area is the nature of the underlying deposits. The sub-carse deposits here consist chiefly of sand and gravel which contrasts markedly with the situation to the west where the silts and sands of the buried beaches are most common. The increased porosity of the gravel would allow easier drainage than relatively compact silty sand or clay and it is suggested that this is a further reason for the tough nature of the carse-clays of this area. It can be noted also that east of Stirling where the buried beaches are again more extensive the carse is generally softer and more easily penetrated.

Although certain obvious differences exist between the Blairdrummond-Stirling area and adjacent parts of the carse, in terms of agricultural geography and morphology it is only when the stratigraphy is examined that a more important difference comes to light. The buried beaches that are so conspicuous in the Thornhill area are of extremely limited extent here, their position immediately beneath the carse being taken by widespread sand and gravel deposits. These can be followed for some 7-8 km in an east-west direction and in all cover an area of 25 sq km, contrasting with the few hundred square metres of buried beach sediments in this area.

Information on the sub-carse deposits is provided by 290 boreholes, most of which reach only as far as the surface of the buried gravel due to the limitations of the Hiller borer. However, in the Carse of Lecropt 75 recently completed commercial boreholes give a description of the composition and thickness of the gravel, while a further five provide information on the area from which the Teith enters the carse. Apart from those at Lecropt, both hand auger and commercial boreholes are generally unevenly distributed. A traverse from Ochtertyre House in a south-westerly direction through the Nyadd towards the Forth accounts for 45 holes while 73 are located in the vicinity of the Hill of Drip because of the complexity of the deposits at that point. The remainder are located according to no set pattern, but at points where earlier investigation showed that they might provide useful information.

An early reference to the buried gravel is to be found in the Old Statistical Account of Scotland for the parish of Kincardine, published in 1791 (Chapter I). There, the chronicler refers to the gravel and notes that it dips towards the Forth with a gradient of one in one hundred, but fails to mention its altitude or overall distribution. The present investigation shows that, from a high point near Blairdrummond, the gravel slopes south, east and west, taking the basic form of an asymmetrical fan with its apex at the mouth of the Teith valley and its eastern margin elongated through Lecropt as far as Stirling. On its southern edge, the fan is limited by the buried valley of the Forth although in places the margin is very indistinct for the finer deposits of the fan are similar to those of the buried valley. The presence of shell fragments in the latter aids differentiation, but they are not always encountered.

Followed northwards into the valley of the Teith, the gravel passes out from beneath the carse-clay to form river terraces that are considered to have been produced by the deposition and dissection of outwash (Smith, 1965). This being so the buried gravel can be regarded as fluvioglacial material carried out into the Forth valley in the form of an outwash fan, elongated in the direction of the Stirling gap. In accord with a fluvioglacial origin is the variability of the deposit which can change from large gravel to coarse sand to mixed sand and gravel in a relatively short horizontal distance. In addition, the sediments appear to become finer away from the apex of the fan. This is most obvious at Blairdrummond where the deposits near the Teith tend to be large or medium gravel, often quite angular, with the occasional layer of coarse sand while to the south the sand becomes predominant until near the Forth the outwash sediments are very difficult to distinguish from the deposits of the buried valley. It might be expected also that the fluvioglacial material would become finer towards Stirling and this is evident to a certain extent. However, gravel is still found in large quantities at the eastern end of the area. It is possible that the Allan Water has provided some of this, but the amounts involved suggest that this is not the sole cause. The formation of these features together with their age and relationship to the deposits of the Teith valley will be discussed in greater detail in Chapter VII.

Information on the thickness of the sand and gravel proved difficult to obtain for much of the area, due to the limited capabilities of the Hiller borer. However, as noted, a number of commercial borehole logs were made available for the Carse of Lecropt and the area near Stirling. The only deep borehole west of the confluence of the Forth and Teith is a well-bore at Nyadd Farm. Here, the sand and gravel is 3.5 m thick lying on a 4.9 m bed of "clay and stones" (till?) that in turn rests on Old Red Sandstone, rockhead being at 0.5 m O.D. Off the carse and into the Teith valley the gravel is as much as 8.4 m thick but the figures here and at the Nyadd are small compared with those at Lecropt where thicknesses of over 12.0 m are common and a maximum of 19.1 m is recorded. In a case such as this the sand and gravel does not normally form one homogeneous stratum but rather a number of layers varying according to the proportions and size of the constituent particles. For example, in the bore that produced the maximum thickness, the log gives the following description of the strata:-

Stratum	Thickness in metres
9. Soil	0.2
8. Mottled clay	1.7

7.	Grey silty clay	7.6
6.	Loose gravel	2.7
5.	Sand and fine gravel	6.7
4.	Coarse sand	7.6
3.	Sand	2.1
2.	Clay and stones	0.6
1.	Rockhead	

Such a situation is quite common and may reflect several factors such as the changing position of the outwash streams and their varying competence.

Despite the limited number of boreholes penetrating the gravel, sufficient reach its surface to permit a reasonable description of its altitude and form. The greatest altitude is not found at the apex of the fan, as might be expected, but a few hundred metres to the west where a value of 11.6 m O.D. is recorded. This may be explained by erosion caused by the Teith when that river became the dominant path for water from the valley after the major portion of the fan had been formed. An illustration of this can be seen in Figure IV.2 where a former course of the Teith is indicated near the northern end of the traverse. It takes the form of a valley 400 m wide and 2-3 m below the general level of the gravel surface. A further point that emerges from this figure is the relatively level surface of the gravel to the north of the Nyadd whereas to the south of the rock it dips gently towards the Forth. Redistribution of the deposits by the Teith may partly explain this also. A line joining the top of the gravel in boreholes 264 and 252 would continue the general gradient of the surface north of the Nyadd and it seems

THE SUPERFICIAL DEPOSITS OF THE AREA BETWEEN-
——————— BLAIRDRUMMOND AND STIRLING

(The location of each section is indicated in Figure IV.1.)

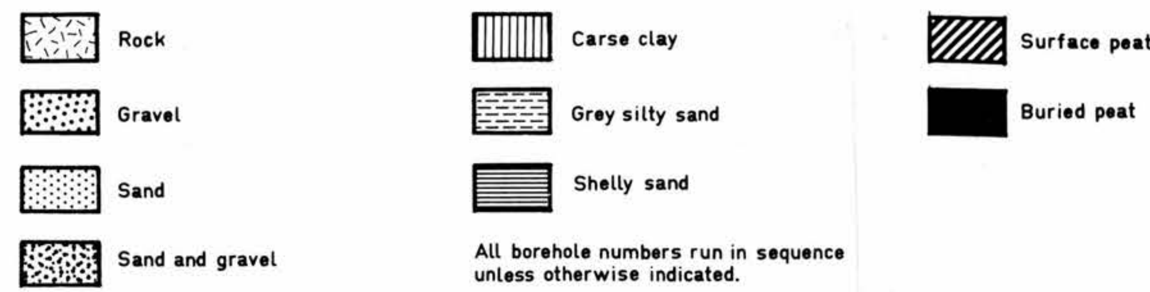


Figure IV.2 Ochtertyre – Nyadd – River Forth

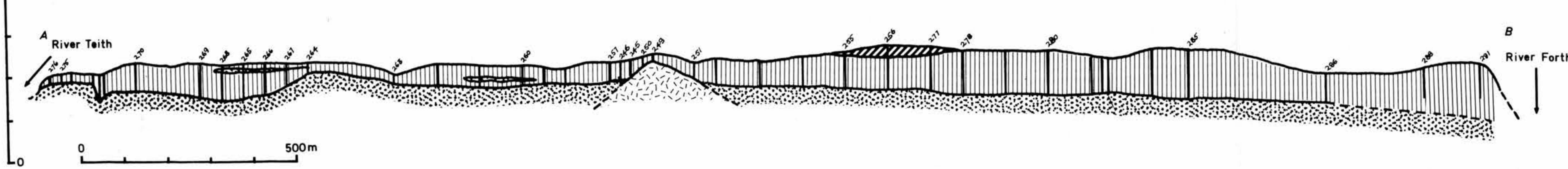


Figure IV.5 Hill of Drip – Cowden

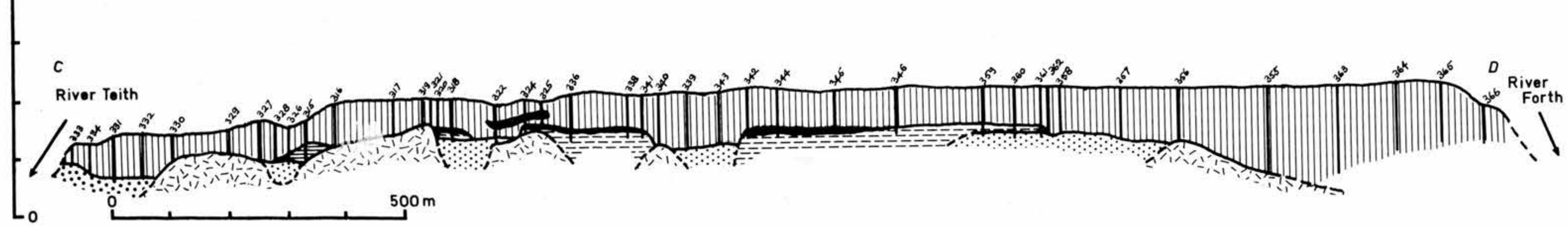


Figure IV.3 Blairdrummond – Stirling (Heights on the surface of the Teith outwash)

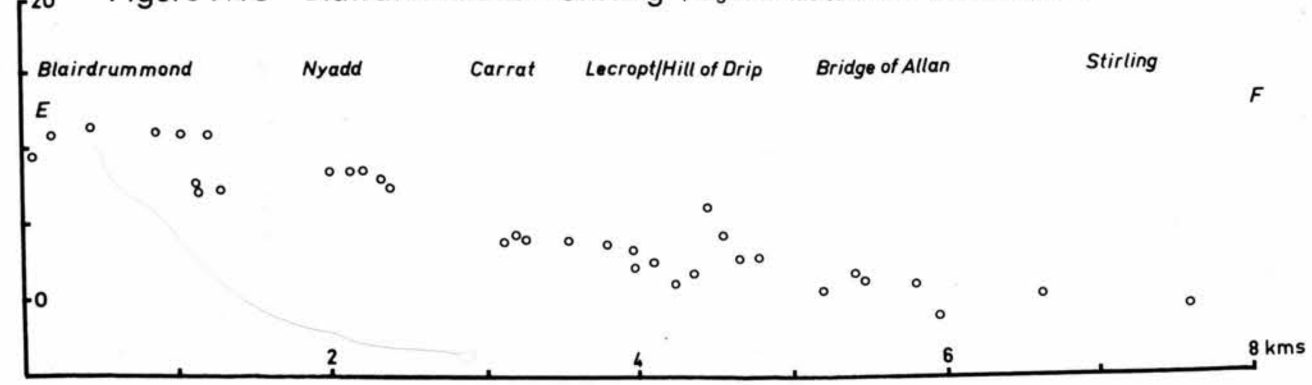
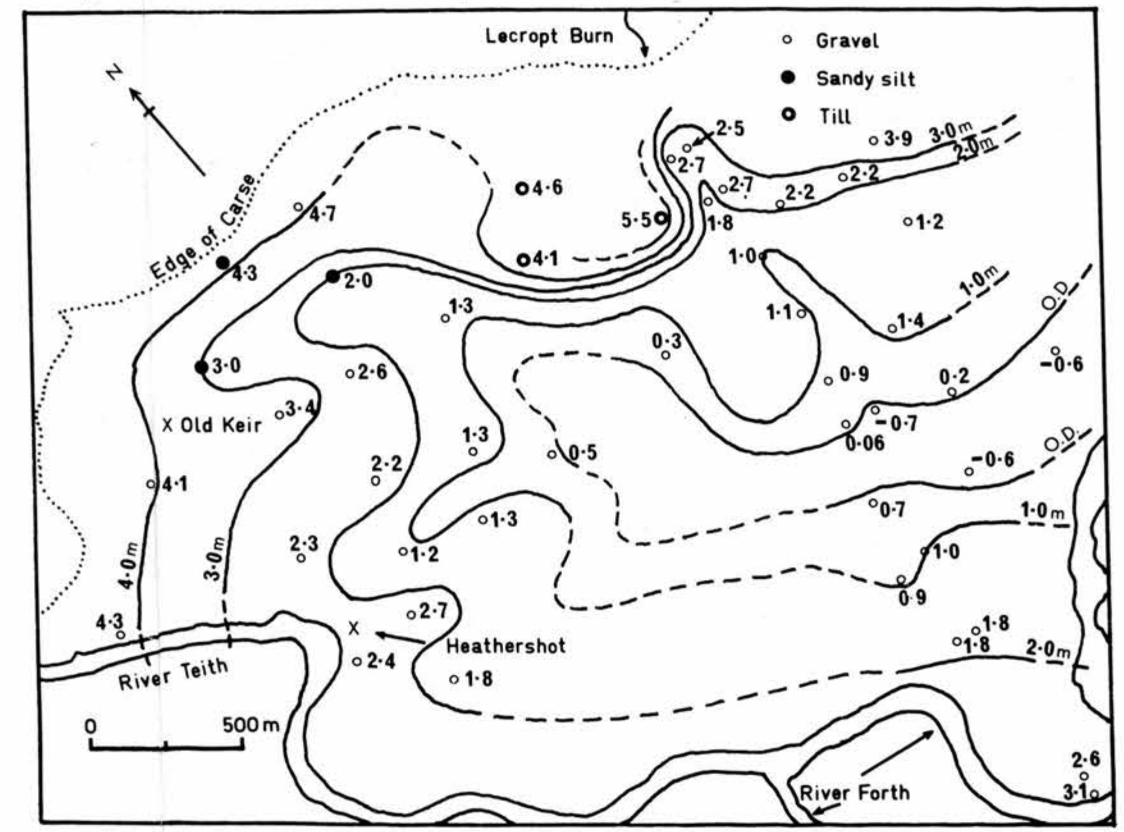


Figure IV.4 Carse of Lecropt (Formlines on the sub-carse deposits)



possible that this situation may have existed at some time in the past, the river later removing some of the deposits to leave the present surface. This suggestion is supported by the presence of sand and gravel lenses in the lowest metre of the carse, showing that the Teith has, in fact, altered its course at different times in the past.

From a height of 9.9 m O.D. near Ochtertyre House, the gravel surface falls away in a south-westerly direction to 8.2 m at the Nyadd, 6.4 m beneath Ochtertyre Moss and a low of 4.7 m O.D. at about 400 m from the River Forth. These figures give an average gradient of one in three hundred which compares with results of one in a hundred or one in two hundred quoted for outwash by Flint (1961). The discrepancy is not serious and may well be explained by the fact that Flint's results do not refer to deposits that have been buried beneath several metres of carse-clay.

As already noted, the highest point recorded on the gravel is 11.6 m O.D., reached near the western limit of the area. From here, the surface slopes quite sharply with a gradient of one in one hundred to the west (Fig.III.9) and has been followed down to 9.5 m O.D. Undoubtedly it descends lower than this, but it could not be located owing to the presence of tough grey silty sand overlying it.

In addition to the southerly and westerly slopes, there is also a marked slope towards the east and this is perhaps the most impressive. It can be traced over a distance of 7 km, as far as Stirling where at a number of points its surface lies below sea-level. Heights recorded along a line running from Blairdrummond in a direction slightly south of east give an indication of the slope.

At Blairdrummond the height of the gravel surface is 11.6 m O.D., but by the time the Nyadd is reached this has been reduced to 8.6 m and within a kilometre of the latter it has fallen to 4.3 m. The slope continues eastwards to 3.1 m at the Hill of Drip, 1.8 m at the southern edge of Lecropt Carse and reaches a minimum of -0.4 m O.D., immediately west of Stirling. It is considered that these figures are representative of the slope involved, but a more comprehensive coverage may be obtained from Figure IV.3.

In the Carse of Lecropt the number and distribution of the boreholes has allowed form-lines to be drawn on the surface of the gravel and this confirms the general eastward slope of the surface of the deposits. Indeed, the slope increases through this area, the surface falling from a height of 4.3 m O.D., in the west, to -0.6 m O.D. near the Allan Water, little more than 2.0 km away to the east. This increase in the gradient is due to the fact that, at Lecropt, the gravel takes the form of a broad, complex valley, the lower altitudes occurring within this valley. Figure IV.4 suggests that at some time in the past, the River Teith continued its course eastwards at Heathershot to produce this valley. In doing so, it may have been aided by water flowing from a valley north-west of Old Keir and from the Lecropt Burn. Presumably, this water went on to meet the Forth, but the exact location of the confluence cannot be determined, for, nearer Stirling, the stratigraphy becomes very complicated, largely due to the effects of the constriction of the valley on erosion and deposition. A whole range of deposits is encountered, from pure gravel through gravel mixed with clay, to sand and gravel and pure sand, all lying beneath a blanket of carse.

They vary in height from -0.4 m O.D. to 7.7 m O.D. and as a result are very difficult to correlate. In addition, the presence of the town limited boring and information had to be obtained from only a few commercial bores. The form of the sub-carse deposits in the vicinity of the Stirling gap, and the relationships between them, is therefore very difficult to establish.

Although commercial boreholes are restricted in their usefulness in many instances, because of missing altitudinal data or lack of locational information, they have the advantage of greater penetration compared with a hand-borer. The Carse of Lecropt borehole logs are most informative in this respect, giving the stratigraphy down to rockhead in several cases. Often the rock-type is not differentiated, but a number of records refer to "sandstone" or more particularly "red sandstone" corresponding to the Old Red strata of the geological maps of the area. The altitude at which rockhead is encountered ranges between 3.8 m O.D. and -19.5 m O.D., with a number of the sub-zero heights located beneath the valley in the sand and gravel, although by no means confined to it. This points to the possibility that the valley was not formed entirely by river erosion and it is suggested that the Teith took advantage of an already existing depression -- probably ice-eroded -- when it followed a more northerly course through this area.

In one or two places, bedrock is overlain directly by gravel, but it is more common for these strata to be separated by other deposits. Of these there are two that are most important. In a total of 35 boreholes penetrating the gravel, 14 show the sub-gravel deposits to be grey or brown sandy silt while 11 refer to firm brown till or firm sandy clay and stones in a similar position. Most logs refer to "till" by name, although those mentioning "firm clay and stones" or "firm sandy clay and stones" were taken to indicate till. Several bores include both deposits and where this is so the till lies beneath the sandy silt.

The former has no obvious pattern to its distribution and it varies in thickness from as much as 9.4 m to as little as 0.6 m, while occasionally it is not present at all. In some cases it is possibly not recorded due to the insufficient depth of the borehole, but in at least six places rockhead is noted without the presence of till. The colour of the till is normally recorded as red and this accords with the solid geology of the immediate area.

With an average thickness of 9.6 m, the sandy silt represents an important facet of the stratigraphy. In addition, these sediments, with some associated clayey sand, cover an area of almost 2.5 sq km and this, along with the thickness and composition of the deposit, suggests formation within a water body of considerable extent. The surface of the sediments shows fairly large height differences, but this may be explained by erosion subsequent to its formation. Whether the sandy silt is lacustrine or marine-estuarine in origin is not clear, for there is no record of varves being present and only one reference to shell fragments associated with it. However, this factor, along with the time of formation of the deposit will be considered more fully in Chapter VII.

In an area notable for the widespread distribution of sand and gravel, a major anomaly is a gravel-free section situated in the northern part of the Carse of Lecropt. Here, boreholes through the carse-clay pass directly into the sandy silt or till that normally lies beneath the gravel. The area is long and narrow -- 1.6 km by 400 m -- with its long axis lying roughly east-west and completely surrounded by gravel. Two basic possibilities exist for an explanation of this feature. Either, gravel was deposited in this area and subsequently removed by erosion, or, for some reason, no gravel was deposited here. In this case, it appears that both possibilities might apply.

Three boreholes in the western part of the gravel-free area show sandy silt or sandy clay immediately beneath the carse while, to the east, till occupies this position. The surface of the silty sand lies at an altitude similar to that of the surrounding gravel and when formlines on the gravel are continued over the silty sand they indicate a valley extending northwestwards beyond Old Keir. It is suggested that the formation of this valley brought about the removal of the gravel. On the other hand, in the eastern part of the gravel-free area, the till stands 2-3 m above the general level of the gravel surface and it seems likely that it remained above the gravel during the deposition of the latter. Thus, despite the general simplicity of the outwash fan, areas such as this make it apparent that this aspect must not be over-emphasised.

Having examined the deposits below the buried gravel, those resting on it can now be considered. It was noted that at Blairdrummond the silty sand of one of the buried raised beaches overlapped part of the western margin of the Teith fan at heights between 9.0 and 10.0 m O.D. Bearing this in mind and considering the fact that large areas of the fan descend below this altitude, it might be expected that at least a moderate proportion of the gravel surface would carry a cover of buried beach sediments. Even taking into account the eastward slope of the beaches, which would limit the area in which they could be deposited, the buried beaches in this area are very small indeed. The reasons for this may not be so complex as would at first appear but they can be more suitably covered below (Chapter VII) and here, the beaches will be examined in terms of location, altitude and composition.

In this whole area of some 25 sq km, buried beach sediments cover no more than a few hundred square metres. Most of this area is located near Hill of Drip with one small patch at Sommer's Lane, Blairdrummond and possibly another at the northern edge of the Carse of Lecropt where grey silty sand is recorded in one borehole at 5.8 m O.D. At Sommer's Lane, grey-green silty sand rests upon medium to large gravel in four boreholes and has an average thickness of slightly over 23 cm. No peat is to be found between the carse clay and the silty sand, but in one case shell fragments are present in this position. The four heights on the surface of the silty sand lie within the range 8.2-7.5 m O.D., which corresponds to a number of heights on the Main Buried Beach between Coldoch and Woodlane.

At Blairdrummond, where the gravel passes below the buried beach sediments, it might be expected that an apron of silty sand would exist as an almost continuous deposit over the margins of the outwash fan, indicating a former incursion of the sea over the gravel. This would take the form of a semi-circular band of grey silty sand along the southern extensions of the outwash from Woodlane to the Hill of Drip. However, between Sommer's Lane and the Hill of

Drip, the silty sand is absent. West of Sommer's Lane, the distribution of boreholes is such that a narrow strip of buried beach may exist between there and Woodlane, although none has been located. If this did exist, it would increase the area of buried beach sediments resting upon the gravel by several hundred square metres, but the total amount would remain extremely small compared with the area of gravel as a whole.

In the vicinity of the Hill of Drip, solid rock is encountered within a few metres of the surface in several places, but the Hill itself is the only point where it rises through the carse. Outwash, represented by coarse grey-brown sand with the occasional patch of gravel, has been deposited around and upon these rocks and in two, possibly three, places the sand takes the form of a channel-fill between rock walls (Fig.IV.5). Of 17 heights obtained on the surface of the sand, 10 lie within the range 6.3-6.7 m O.D., but towards the River Teith, 3 boreholes (326-328) give heights, on sand filling a channel, of 4.3, 4.4 and 4.6 m O.D. The height difference may be associated with the erosional and depositional activities of the Teith, for nearer the river, gravel is encountered at 2.9 m O.D. and, from the form of the carse surface, it is apparent that the Teith has not always followed its present course.

The buried beach deposits of this area rest upon the coarse sand and produce a platform of sediments around the Hill of Drip. A few hundred metres to the south-west lies another patch of sediments, the two being separated by a narrow valley floored with coarse grey-brown sand. It was not possible to verify the presence of the sand in all boreholes, but the succession from carse-clay, through buried peat and grey silty sand to coarse grey-brown sand, occurred in sufficient cases to show that it was meaningful. Where the succession was found, the beach deposits averaged 34.0 cm in thickness, but in other places they have been penetrated to depths of 44.0 and 60.0 cm without the coarse sand being reached. In the majority of cases, however, penetration beyond the upper few centimetres was not achieved, due to the toughness of the silty sand.

The buried beach sediments of this area are essentially similar to those found to the west of Blairdrummond, in terms of both colour and composition. They consist basically of fine grey or grey-green silty sand containing a high proportion of micaceous fragments. The upper few centimetres often contain a considerable amount of clay and this may form a distinct layer in which the clay is predominant (Boreholes 306, 307, 308, 336, 345 and 346). Although the grey silty clay is very similar to that of the Low Buried Beach near Thornhill, the cover is not complete and its distribution is reminiscent of the clay patches on the surface of the Main Beach east of the Goodie Water.

Like the beaches further west, that at the Hill of Drip is covered by a layer of peat. It is a relatively thin layer, seldom exceeding 20.0 cm, but it is extensive, almost entirely covering the surface of the beach. Furthermore, it is commonly a very soft deposit, compared with the buried peat to the west, with little included woody material. Consequently, it is easily penetrated. A lense of peat with a maximum thickness of 67.0 cm, lying entirely within the carse clay, was discovered in boreholes 322-325, apparently having drifted in during the deposition of the clay.

The surface of the buried beach at Hill of Drip has been heighted at 27 points within a relatively small area. Of these heights, 18 lie within the range 7.0-7.9 m O.D., the remaining 9 lying between 6.8 and 7.0 m O.D. To the west, measurements on the Low Buried Raised Beach have produced heights falling into a similar range and at first sight the beach at the Hill of Drip might be placed in that category. Taking isostasy into consideration, however, a slope ought to exist on the Low Beach producing lower heights at Hill of Drip than at Thornhill, some 9.0 km distant. On the other hand, the Main Buried Beach is seen to slope gradually eastwards from 12.5-12.9 m O.D. near the Menteith Moraine, to 9.0-10.0 m O.D. near Blairdrummond. The values at Hill of Drip would continue this trend. This will be examined graphically and statistically (Chapter VIII), but, at this point, taking into account the altitude, form and composition of the deposits at the Hill of Drip, it seems feasible to suggest that they belong to the Main Buried Raised Beach.

A final facet of the sub-carse morphology that can be considered here is the buried valley of the Forth. In this area it is not so marked as farther west, largely due to the presence of the Teith outwash. Towards the southern edge of the fan, the junction between channel and outwash deposits is often very difficult to determine, because of the removal of material from the fan and its subsequent deposition in the valley. Occasionally, the presence of shell fragments allows a distinction to be made. At the eastern edge of the buried beach sediments at the Hill of Drip, the valley is sharply defined (Fig.IV.5) and may have part of its course over solid rock, but beyond this towards the Stirling gap, the nature of the deposition is such that it cannot readily be distinguished.

Conclusion

The carselands lying between Blairdrummond and the Stirling gap are superficially little different from those west towards the Menteith Moraine. However, an examination of the stratigraphy and sub-carse morphology shows a distinctly different area. The following are the main sub-surface features that have been identified:-

1. An outwash fan of coarse sand and gravel, sloping out in all directions from its apex near the mouth of the Teith valley, but attenuated in an easterly direction. From a maximum height of 11.6 m O.D. at Blairdrummond, it slopes eastwards to pass below Ordnance Datum near Stirling. Commercial boreholes indicate that this buried gravel in places masks areas of fine water-laid sediments and till.

2. At Blairdrummond, the western edge of the outwash is hidden beneath the deposits of the Main Buried Raised Beach, indicating the relative age of the two features. The Main Beach has also been identified at the Hill of Drip at heights between 6.8 and 7.9 m O.D. Other patches of beach sediments occur, but to a very limited extent and a characteristic of the area is the general absence of these deposits.

CHAPTER V

THE STRATIGRAPHY AND SUB-CARSE MORPHOLOGY OF THE AREA BETWEEN THE STIRLING GAP AND KINCARDINE-ON-FORTH*

Beyond the limits imposed by the Stirling gap, the carselands again become extensive, particularly south of the River Forth, where an unbroken expanse of carse-clay, 3.0-5.0 km wide, stretches from Stirling to Grangemouth. In contrast, the northern section is rather limited, attaining a maximum of 4.0 km a short distance east of Stirling, before branching to send one narrow arm into the valley of the River Devon and another, nowhere exceeding 2.0 km wide, along the north bank of the Forth as far as Kincardine. The considerable difference in area that this produces is evident from Figure I.1.

Along its northern margin, the carse lies against the Ochil Hills which rise sharply to heights of 350.0-500.0 m above the plain and extend along its edge from Airthrey to Tillicoultry in the Devon valley. The southern arm, between Cambus and Kincardine, is backed by a variety of features, including Carboniferous rock outcrops as well as glacial and raised marine deposits in places. The Forth, providing the southern boundary, changes considerably as it flows eastwards. Between Stirling and Alloa it traces its normal meandering course, becoming gradually wider, but beyond the latter it straightens,

*Figure V.1 is applicable to this entire chapter.

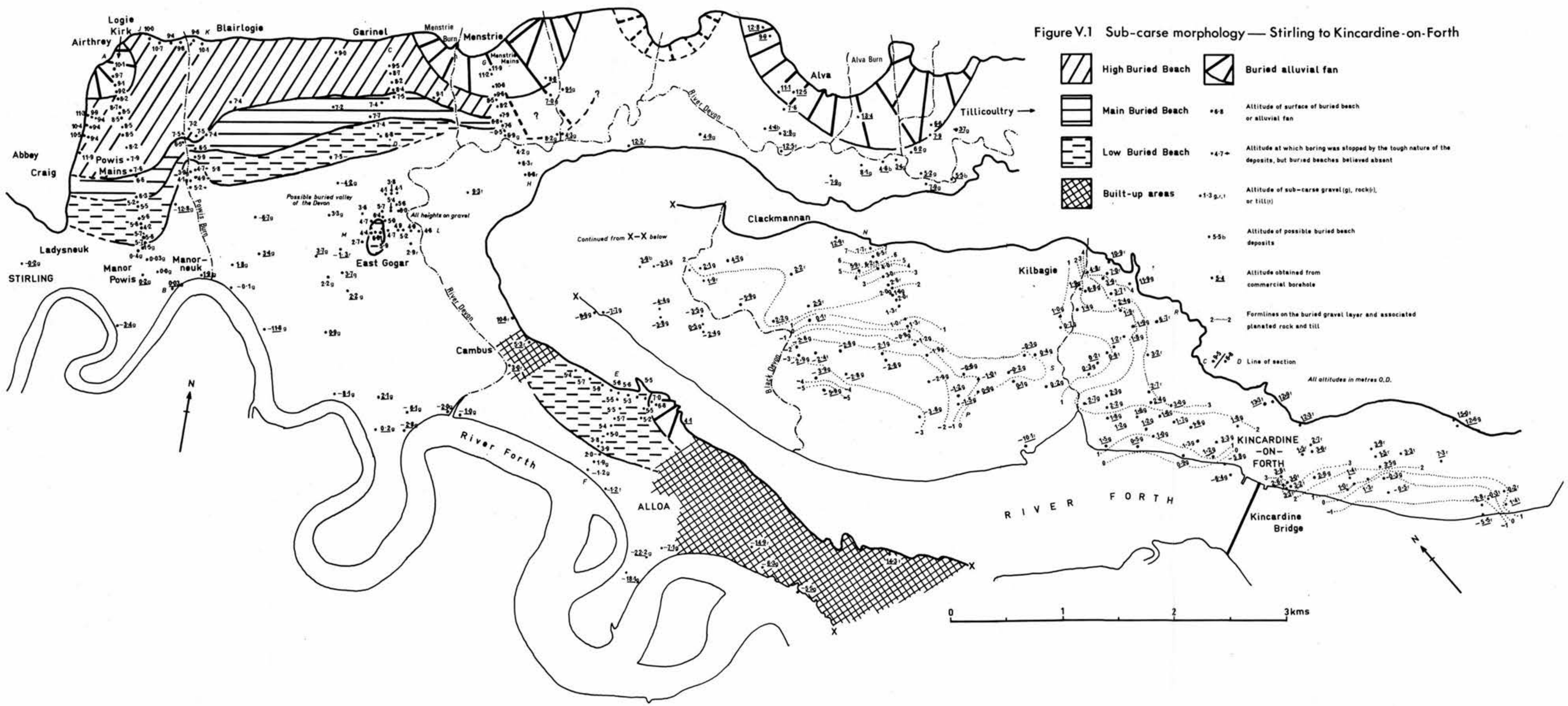


Figure V.1 Sub-carse morphology — Stirling to Kincardine-on-Forth flowing south-eastwards to Kincardine where it widens significantly to become obviously estuarine. For the whole of its passage through the area, the river is tidal.

At first sight, the carse in this area is basically similar to that already described west of Stirling. Closer inspection, however, shows that a number of important differences exist. Smith (1965, 1968) has shown that the surface consists of a number of facets related to different sea-levels in Postglacial times. Several of these have been recognised west of Stirling also, but the differentiation is especially distinct east of the town where a sharp break of slope runs north-eastwards from Abbey Craig towards the Devon valley and another is evident near Cambus. Thus, immediately east of Stirling, before the plain divides, the carse consists of two distinct surfaces, designated Postglacial 2 and 3 by Smith.

Superimposed on this basic division there are other features mainly associated with the dissection of the surfaces. The higher of the two surfaces -- Postglacial 2 -- is strongly dissected, particularly in the vicinity of Menstrie where a number of channels cross the carse in a general north to south direction. Erosion is also evident on the lower surface, but to a lesser degree, and channels originating on the upper terrace often end abruptly at its southern edge or may be continued on the lower surface by much smaller channels. Beside the Forth the carse has been eroded by the river as periodic changes in course have taken place. Below Abbey Craig a large meander scar has been cut in the carse showing that the Forth once flowed almost to the base of the rock.

As well as causing erosion of the carse edge, the Forth has been responsible for deposition in this area, as can be seen near the river, where a considerable proportion of sand is incorporated in the normally clayey carse sediments. Along the northern margins of the plain there is further evidence of deposition. Streams from the Ochil Hills have carried sand and gravel out on to the carse surface, forming a series of alluvial fans at the junction of hill and plain. In times of flood, detritus from the fans may be spread over the carselands, even yet, as stream courses change, but on the larger fans, as at Menstrie and Alva, restriction of the streams by artificial means has reduced this.

In the Devon valley, these fans play an important part in the morphology of the area. At Alva a large fan, extending fully 800.0 m into the valley and more than a kilometre wide, restricts the carse to a few hundred metres in width, while a feature of similar dimensions at Tillicoultry effectively marks the eastern limit of the carse in the valley. Material carried down from the hills by these streams, has been incorporated in the carse-clays producing a tough, relatively sandy deposit, while the Devon itself has been responsible for the deposition of sand along its banks. In the New Statistical Account of Scotland (1841), a similar situation was noted. The chronicler for the Parish of Alva recorded four types of arable soil, reading from the Ochils, in a southerly direction, as follows:-

1. Rich hazel mould, mixed with gravel and small stones.
2. Stratum of moss over a bed of clay, extending from 50-100 yards wide and the moss in some places, 7 feet deep.
3. Strong clay.
4. Haughing ground with sand laid down by 2-3 inundations of the

Devon per year.

In addition to the coarser sediments along the northern edge of the valley and along the river, the presence of the moss is of considerable interest, for, this is the only part of the area east of Stirling and north of the Forth that appears to have carried peat. Elsewhere there is no evidence for a peat cover except along the edge of the Ochils, where thin peat is still present today (Smith, 1968).

Near Menstrie, the Devon leaves its valley and turns sharply southwards across the carselands to meet the Forth near Cambus. In this section, the river follows a meandering course and there is ample evidence that it has changed position a number of times. Near East Gogar a particularly well developed meander scar is encountered with coarse sandy deposits at its base and in the arc between it and the present river course (Boreholes 566, 567 and 568). Adjacent to this, sandstone is present in the bed of the river. In places, an attempt has been made to maintain the Devon's present course by strengthening the banks and building artificial levees. This is evident near East Gogar and at the confluence of the Devon with the Forth.

Eastwards from Cambus, the northern carselands are relatively narrow and consist, according to Smith (1968), of a surface transitional between the two lowest carse levels as well as a surface representing the lowest level, namely Postglacial 4. In addition, near Kincardine, a limited area of reclaimed land is encountered near the river and this is very similar to the carse in terms of composition and texture, although at a lower altitude. These features are not always readily distinguishable without some form of measurement and in this region in particular, the carse surfaces are increasingly obscured or interrupted by industrial activity or by the expansion of the towns of Alloa and Kincardine. Coal mining has been of considerable importance here since the mid-19th century and indeed from Stirling eastwards there is evidence for this in the form of increasing mining subsidence which is pronounced between Stirling and Alloa as well as in the vicinity of Kincardine. Such a situation imposes problems involving the measurement of the carse surface and the correlation of sub-carse deposits. However, the mineral and industrial activity was often preceded by extensive borehole investigation, which has led to the availability of a large number of borehole logs for the area.

The sub-surface investigation of this area is based on 236 shallow boreholes used in conjunction with some 250 commercial boreholes, provided by the Geological Survey and local authorities. Certain problems arose with the commercial bores mainly with reference to missing altitudinal information and individual interpretation of strata. The former was resolved by comparison with heights obtained in the measurement of the shallow bores and although these do not have the accuracy of levelled heights, it is considered that the majority of the estimated values lie within ±0.3-0.5 m of the true height. In the case of the stratigraphical interpretation, the problems were often more involved. Due to individualistic recording by different observers it was found that boreholes separated by only a few metres bore no apparent relationship to each other. In some cases, two deposits referred to by the same name, for example, "clay with stones", in adjacent boreholes, were not always the same deposit as altitude and position in the stratigraphical column showed. Where this was so and the borehole coverage sufficiently extensive, it was usually possible to resolve the differences, but not in every case. In a number of borehole logs, the sub-carse deposits had to be combined as "drift" leaving the borehole suitable only for the estimation of the height of rockhead.

Despite these difficulties, the borehole logs give a good indication of the distribution of the various sub-carse deposits. Buried raised beach sediments again make an appearance on a scale similar to those west of Blairdrummond, but here, their morphology is much more varied and their relationship to each other much more complex than in the area previously described. Coarser deposits associated with the Devon and the numerous minor streams issuing from the Ochils are widespread, while farther east towards Kincardine, gravel, till and solid rock are encountered immediately beneath the carse-clay.

The most extensive of the buried beach sediments is the pink silty sand of the High Beach. Bounded on the west by the high ground between Abbey Craig and Airthrey, the beach extends for 4.0 km along the base of the Ochils before dying out against the buried extension of the Menstrie alluvial fan. It reaches a maximum width of almost 1.0 km near its western end but gradually narrows eastwards until at Menstrie it is little more than 100.0 m wide. Like the High Beach near Thornhill, penetration with the Hiller borer beyond the upper few centimetres is virtually impossible and as a result no estimate of the general thickness of the deposit can be made. Along the inner margins of the beach, the silty sand thins out and the underlying sediments can be reached, but obviously such conditions are not representative of the deposit as a whole.

The composition of the pink beach in this area is variable. Near the Ochils and along the inner margin, in general, the deposit can be recorded as "coarse pink silty sand" very similar to the sediments of the High Beach west of Blairdrummond. In places, the silty sand is more brown than pink and this, together with the coarse nature of the deposit, appears to have been brought about by the addition of material carried down from the Ochils as the High Beach was being formed. Away from the backslope, towards the southern edge of the beach, boreholes still record the presence of pink silty sand but much finer pink clay is increasingly encountered. Although no sharp boundaries can be drawn between the areas of pink clay and the areas of pink silty sand, the general distribution of the two deposits is largely to be expected, showing as it does, an increase in the proportion of coarse sediments as the former shoreline is approached. The pink clay is most common on the western portion of the beach where it is widest. Farther east, as the beach narrows and the outer edge is effectively closer to the source of coarser materials, in the hills and the Devon valley, pink or brownish-pink silty sand supplants the clay.

A characteristic feature of the High Buried Beach, as described in the Thornhill area, was the presence of a grey coloration in the upper few centimetres of the otherwise pink beach. This is repeated in the area now under consideration, where the grey colour is commonly restricted to the upper 15.0-20.0 cm. It has been suggested that this does not represent a separate deposit, but rather indicates a modification of the upper portion of the beach by some agency such as weathering (Sissons, 1966) and there is evidence for at least the first part of this statement, in the High Beach east of Stirling. Firstly, there is a close continuity between the two sediment types, as far as composition is concerned. Where the beach consists of pink clay, the upper grey portion is invariably clay also and, where pink silty sand is the main deposit, the uppermost part is composed of grey silty sand. This can be seen in the borehole logs, but when seen in section the relationship is more obvious. In the wall of a ditch opened up during the laying of a pipeline near Menstrie, the beach and associated deposits were exposed over a lateral distance of 2.0-3.0 m (Fig.V.2). Beneath the carse-clay and some surface sand, a layer of compressed vegetable matter, no more than 2.0-3.0 cm thick covered the 10.0-15.0 cm of grey silty sand and passed rootlets through it into the pink sediments below. Inspection showed the junction between the upper grey and lower pink silty sand to be somewhat diffuse, the grey colour gradually giving way to the pink. In addition, the junction was not straight, but took the form of a wavy line as if grey stain had been poured on to the surface and seeped through into the beach before drying. Taking the above evidence into account it appears that the grey silty sand can be regarded as an integral part of the High Buried Beach, the coloration being due to weathering or perhaps leaching that took place while the beach formed a land surface prior to its flooding by the carse sea.

Almost everywhere, the High Beach carries a peat cover that is normally very soft with only a few patches of woody material. In a number of places, the upper few centimetres of the peat are mixed with the overlying carse-clay but the junction of the peat with the buried beach sediments is usually quite sharp. The thickness of this peat layer varies from place to place, but there is a distinct pattern to the variation. Its greatest thickness is recorded near the western end of the beach where it exceeds one metre in a number of boreholes near Powis Mains. Followed eastwards a gradual thinning of the buried peat takes place, through an average of 40.0 cm at Blairlogie, down to 10.0 cm at Garinel and less than 5.0 cm at the eastern end of the beach. The possibility exists that this gradual thinning of the peat is related to changes in the composition of the buried beach. It has been pointed out above that the western part of the beach contains a considerable proportion of clay while towards the east, coarser silty sand is encountered. It is suggested that the relatively poor drainage of the clay areas, as compared with the areas of silty sand, would encourage a thicker growth of peat on the former.

Measurements at, or near, the back edge of the beach show that a maximum height of 10.7 m O.D. is reached between Logie Church and the village of Blairlogie. Most heights in the western part of the area, however, fall within the range 9.4-10.4 m O.D. One kilometre east of Blairlogie, the beach lies at 8.7 m O.D. and at Menstrie it has fallen further to 7.9 m O.D. Between Logie and Abbey Craig, the former shoreline trends roughly north-south and here heights lie between 9.4 and 9.9 m O.D. Along its southern edge, the height of the beach varies between 7.7 m O.D. in the west and 7.3 m O.D. near its eastern end.

Superimposed upon this general distribution of heights are a number of points where the surface shows considerable variation over short distances (Figs.V.3 and V.4). Two factors appear to explain this. In the first place, while the beach was in the process of formation, the nature of the backslope, with its steep gradients and numerous streams, must have led to the deposition of large quantities of relatively coarse material along the shore. Thus, although the figures quoted above indicate a general slope from west to east -- a slope that might be expected from a consideration of other Late and Postglacial raised beaches in Central Scotland -- there are local irregularities that should be taken into account when the shoreline is being examined. Away from the shoreline itself, erosion has played a part in disrupting the surface of the beach. This is perhaps best seen in the section at Garinel (Fig.V.4) where dissection is particularly strong. Marine activities seem to have been effective at the beach's southern edge, but it is also possible that at least some of the erosion was caused by streams flowing from the Ochils across the High Beach in much the same way as the present streams flow across the carse, and the Powis Burn shows evidence of this in the form of a buried gully where it crosses the outer edge of the beach.

At a point some 150.0-200.0 m inside the southern limit of the High Buried Beach it is not uncommon for a sharp change in height to take place (Figs.V.4 and V.5). Although the elements of the stratigraphy remain essentially the same, changes take place in the thickness of particular deposits and the surface of the beach diminishes in absolute height by 0.3-1.0 m. The normal stratigraphy of carse-clay and buried peat overlying buried beach deposits of

THE SUPERFICIAL DEPOSITS OF THE AREA BETWEEN–
——— STIRLING AND KINCARDINE–ON–FORTH

(The location of each section is indicated in Figure V.1.)

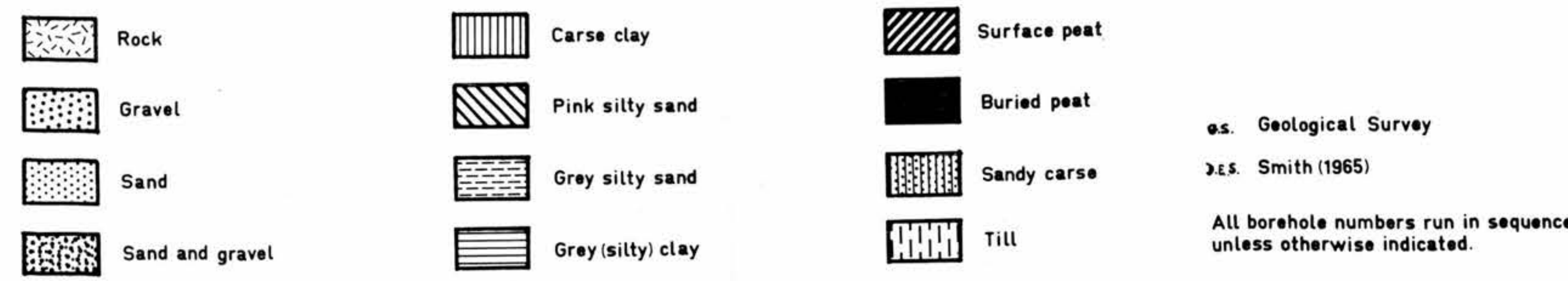


Figure V.5 Logie Kirk – Manor Powis

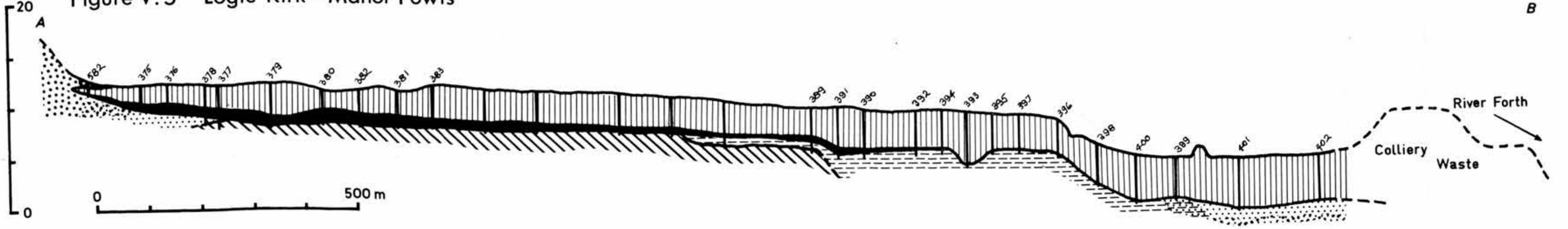


Figure V.4 Garinel

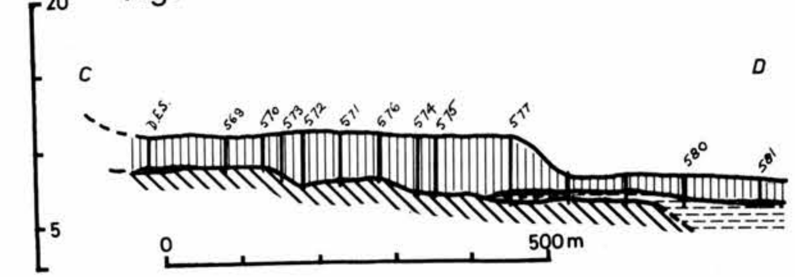


Figure V.6 Cambus

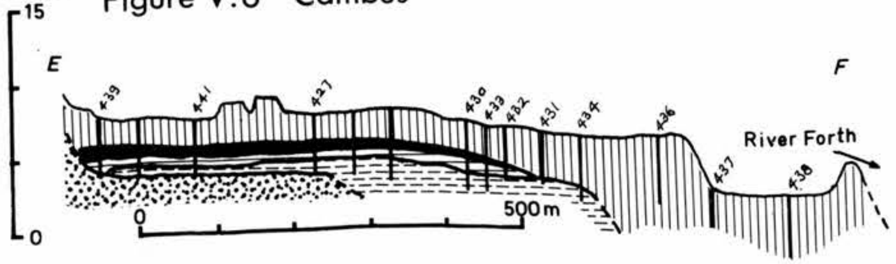


Figure V.7 Menstrie Mains – River Devon

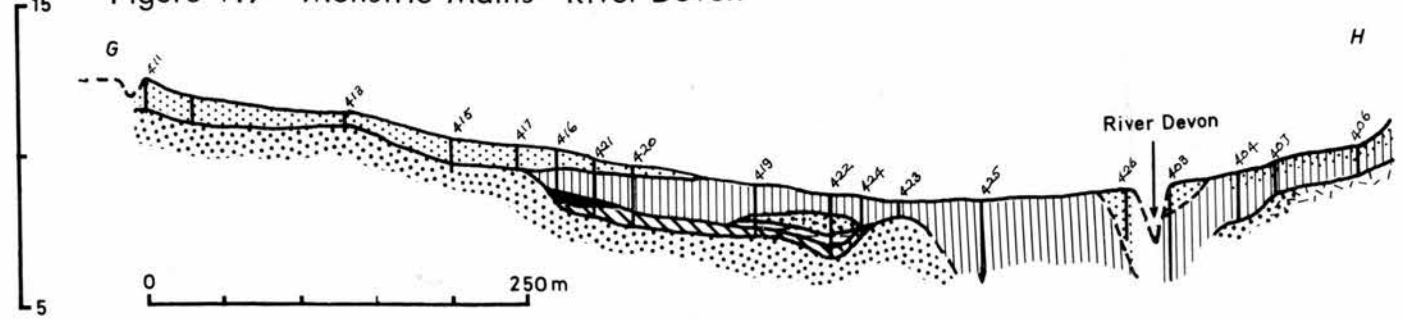


Figure V.2

Stratigraphy near Menstrie Mains

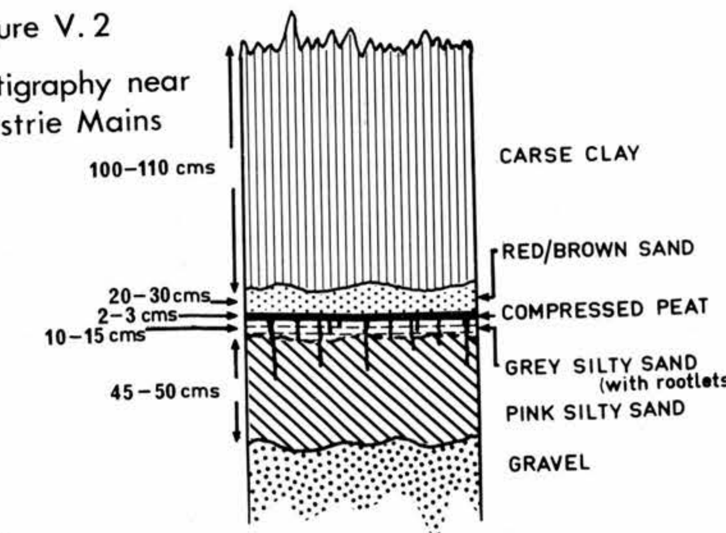


Figure V.3 Blairlogie

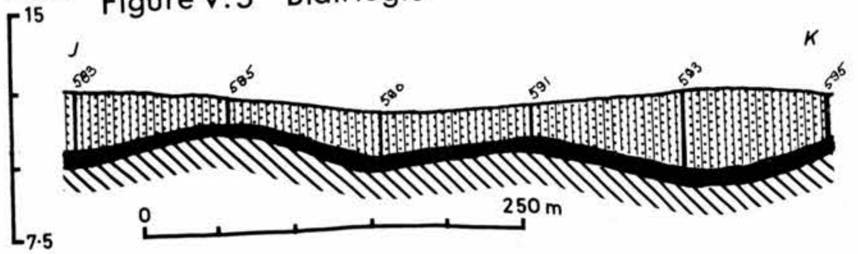


Figure V.8 East Gogar

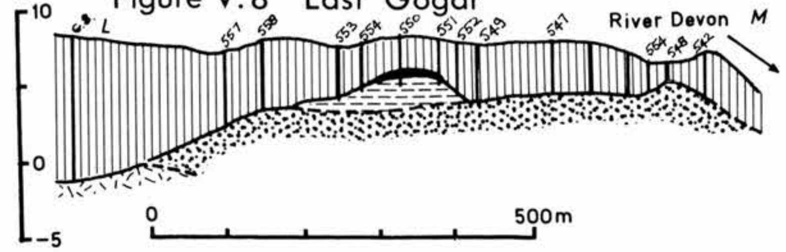


Figure V.9 Kincardine *(Based on commercial boreholes)*

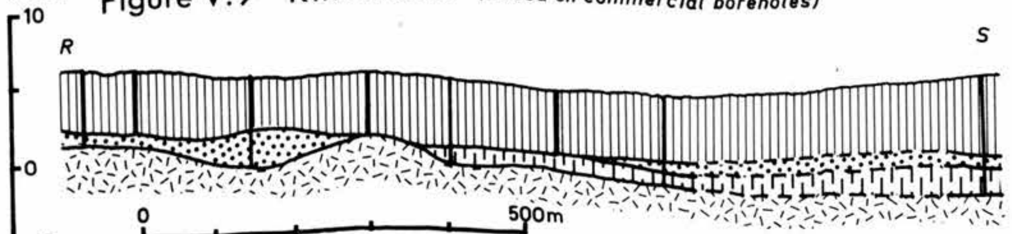
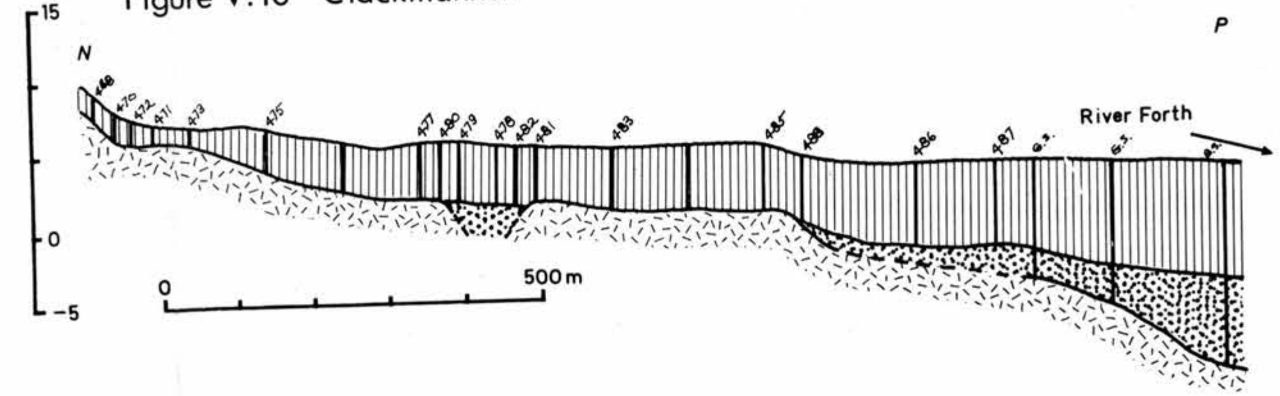


Figure V.10 Clackmannan



grey and pink silty sand is still present but the layer of grey silty sand is usually thicker. On the higher part of the beach the grey deposit reaches a maximum thickness of 15.0-20.0 cm but is often less, whereas on this lower portion, thicknesses of over 30.0 cm are commonly recorded, with a maximum of 48.0 cm. It is suggested that the grey silty sand on this lower part of the High Buried Beach is of different origin from that on the main, upper portion.

The stratigraphy indicated above is present over a north-south distance of never more than 200.0-300.0 m beyond which the grey silty sand is still present but at a slightly lower level, and the sediments of the High Beach are no longer encountered. A number of boreholes, put down to depths of more than a metre below the normal level of the pink silty sand failed to locate it. It is possible that the pink sediments are present at even greater depths, but, by comparison with the High Beach in other localities this is considered unlikely. The grey silty sand, with isolated patches of grey clay on its surface, extends for several hundred metres beyond the edge of the pink deposits, before ending equally abruptly.

Considering the position and relationship of these deposits, it is evident that two beaches exist along the southern edge of the High Beach. The higher of the two would seem to indicate a period of erosion during which a step was cut in the pink silty sand and covered by a layer of grey silty sand. Subsequently the sea-level fell by 0.3-0.5 m to produce the lower beach. These two beaches, while differing in stratigraphy and composition from the lower beaches in the west, occupy a similar position to the latter with respect to the High Beach and for this reason the composite feature overlying the edge of the High Beach east of Stirling has been provisionally equated with the Main Beach and the lower feature with the Low Beach. Further discussion on this point will be presented in Chapter VII.

The Main Buried Raised Beach is relatively limited in extent east of Stirling, being no more than 300.0 m at its widest point. It stretches from Abbey Craig in a direction slightly north of east for nearly 4.0 km before ending against the alluvial fan of the Menstrie Burn. The grey silty sand, of which the beach surface is composed, bears a strong resemblance to that forming the Main Beach in the west, but the pink silty sand underlying the grey appears to have no counterpart in the west. It might have been expected that the period of erosion that accompanied the formation of the Main Beach east of Stirling would have manifested itself in a similar way west of Blairdrummond, where the buried beaches are extensive. However, the junction of the High and Main Beaches in that area is marked by the buried valley of the Goodie Water and this could have destroyed any evidence that existed. Furthermore, the isostatic recovery of the High Beach prior to the development of the Main Beach would produce a greater height differential between the two in the west than in the east, lessening the likelihood of erosion in the former area.

Like the Main Beach, the Low Beach in this area is of no great extent. It occupies a narrow strip, no more than 400.0 m wide, along the edge of the Main Beach and extends eastwards to the vicinity of the Menstrie fan where it loses its identity in the complex stratigraphy associated with that feature. In addition, a small area of grey silty sand and clay near East Gogar reflects the characteristics of the main body of the beach although well separated from it. The Low Beach is composed mainly of grey silty sand similar to that of the Main Beach. A distinction can be made, however, for the upper few centimetres of the former are often rich in clay. In places, the clay stands out as a separate layer distinct from the silty sand beneath and, although the cover is by no means continuous, thicknesses of as much as 35.0 cm have been recorded.

Over both lower beaches there is a thin and very variable cover of peat no more than 20.0-25.0 cm thick, but commonly much less. This layer is soft for the most part with little woody material, suggesting that its thin nature is due to the lack of development rather than compression by the overlying carse-clay. On the whole, the buried peat in this area is thinner than that on the lower beaches west of Blairdrummond and this may be related to the earlier incursion of the carse sea in the east.

Both the Main and Low Beaches have been heighted at several points along their respective shorelines and they show a pattern that is difficult to reconcile with that expected for the area in general and the beaches in particular. The values indicate a slight increase in height from west to east in both cases. Near Powis Mains, for example, the Main Beach shoreline stands at 6.6 m O.D., but rises to 7.4 m O.D. in less than a kilometre to the east, until at Garinel a maximum of 7.7 m O.D. is attained. This trend is mirrored in measurements from the Low Beach shoreline, which rises from 5.7 m O.D. to 6.8 m O.D. in the same distance and direction.

In an area such as this where isostatic compensation has produced a slope on the Postglacial raised beaches from west to east (Smith, 1968), it would be in order to postulate a similar slope on earlier beaches. This does not seem to follow in the present case. The uneven distribution of heights, with the greater proportion on the western part of the beach, probably mitigates against too much emphasis on a rise to the east, but there is definitely no evidence for the slope to the east that might have been expected.

The activities of the River Devon may possibly explain this apparent anomaly. At the time of formation of the Main Buried Beach the addition of material at its eastern end by the river may have produced a slope towards the west and since that time the cumulative effects of isostatic recovery have been insufficient to eradicate this trend. It can be argued that the High Beach being in a similar situation should exhibit a similar slope. However, during its development material appears to have been supplied by streams and possibly mass-movement all along the face of the Ochils and the relative importance of the Devon was therefore less. Furthermore, accepting the earlier formation of the High Beach, isostatic recovery, having longer in which to be effective, would have reduced or perhaps even reversed the original slope.

These stretches of buried beach sediments along the southern edge of the Ochil Hills form the main examples of that type of deposit in the area between Stirling and Kincardine. As with the High Beach, there is no evidence that the lower beaches extend into the Devon valley as recognisable entities. In a few commercial boreholes -- no more than six -- buried beach sediments may be represented by patches of grey clay or silt with surface heights estimated at between 5.0 and 7.0 m O.D. and in two cases overlain by peat. Although isolated, all lie close to the present course of the river and may indicate remnants of the Main or Low Beaches. The presence of abundant gravel from the Ochil fans could have prevented the penetration of the sea into the valley, except along a narrow strip adjacent to the main river where grey silty sand and clay was deposited. With the eventual return to a lower sea-level, the Devon could have dissected the sediments to produce the present distribution.

Beside the Forth, between Cambus and Kincardine, only one rather limited area of buried beach has been located. East of the junction of the Devon with the Forth, a patch of grey silty sand and clay lies beneath the northern edge of the carse near Cambus. It has an east-west extent of slightly over one kilometre and a maximum width of some 600.0 m. However, the eastern and western limits have not been located exactly and this illustrates the problems involved in boring in industrial or built-up areas. On the west, the presence of the village of Cambus prevented hand-boring but a combination of excavations within the built-up area and boreholes to the west of it shows that the western edge of the beach must lie somewhere beneath the village itself. On the east, playing fields and railway marshalling yards on the outskirts of Alloa forced an estimation of the eastern limit. Despite this, the area in which the beach was examined supplied sufficient information to enable its composition and form to be noted (Fig.V.6).

A characteristic of the beach sediments in this area is their soft nature, allowing considerable penetration and in a number of boreholes permitting the underlying deposits to be reached. Typically the stratigraphy is arranged as follows:-

5. Carse clay
4. Peat
3. Grey (silty) clay
2. Grey silty sand
1. Sand and gravel

The carse, although relatively easily penetrated, contains a considerable proportion of sand mixed with the clay especially near its inner margin. Shell fragments are also common, either scattered indiscriminately throughout the clay or arranged in beds consisting of shell fragments and sand particles. The former situation is most common, but in eleven boreholes in a very small area the shells lie in recognisable beds with absolute heights ranging between 3.7 and 7.1 m O.D. but with a much smaller variation of 6.1 to 7.1 m O.D. in seven of the holes. The shell fragments are normally of sufficient size to allow recognition and *Ostrea*, *Mytilus* and *Cardium* have been identified, the last two being most common.

A thick bed of peat averaging 58.0 cm lies beneath the carse. It forms a complete cover on the surface of the buried beach deposits and attains a maximum thickness of 99.0 cm. In a number of boreholes the peat is very woody but apart from this it is normally soft with the seed heads and stems of *Juncus* as one of the more easily recognisable constituents. A marked transition zone of as much as 10.0 cm of mixed peat and clay is a common feature of the junction between the peat and the overlying carse-clay but the lower boundary with the grey clay of the buried beach is usually quite sharp with only occasional mixing.

The buried beach sediments in this area consist of two distinct types of deposit. Immediately beneath the sub-carse peat is a layer of soft grey clay or silty clay while beneath this again lies a grey silty sand stratum similar to the deposits forming the Main Buried Beach farther west. With an average thickness of 70.0-75.0 cm and a maximum of over a metre, the grey clay lies in a thick blanket over the silty sand. The cover is virtually complete and only in a few holes near the southern edge of the beach is the clay absent. As well as indicating the thickness of the clay, the bore-holes also indicate the remarkable homogeneity of the deposit in terms of colour and composition. Only in the lowest few centimetres does it change somewhat, becoming slightly coarser as some mixing with the underlying silty sand occurs. Elsewhere it remains soft, sticky, grey clay, not unlike carse clay and very reminiscent of the grey silty clay of the Low Buried Beach near Thornhill.

Measurements taken at eleven points along the back of the beach in a distance of almost one kilometre, show that the surface of the grey clay varies in altitude between 5.9 and 5.3 m O.D. Certain groupings of the figures indicate a slight slope from west to east but with regard to the distance and number of heights involved it would not appear to be meaningful. However, the bore-holes do show a slope on the beach from back to front, producing a height difference of over a metre, the altitude of the outer edge of the feature being as low as 4.5 m O.D.

At the southern edge of the beach, a layer of grey silty sand passes from beneath the clay and as already noted this is a significant feature in the stratigraphy. It lies beneath the grey clay throughout the area except in the narrow band near the southern limit of the beach deposits where the clay dies out and the silty sand lies immediately beneath the carse. As noted the silty sand is normally grey in colour, but in a number of boreholes it takes on a definite pink coloration; for example, near the backslope of the carse and near the base of the deposit where it rests upon gravel. The adjacent slopes partially veneered with till referred to as "clay and stones" in borehole logs, do not appear to contain the materials that would produce the colour change, ruling out slopewash as a possible explanation. However, an examination of the gravel beneath the grey silty sand provides another possibility.

In a number of boreholes that penetrate the grey silty sand, it is found that the uppermost layers of the underlying gravel contain a considerable proportion of pink sand or pink silty sand (Boreholes 445, 448, 452 and 455) that may well represent the re-deposition of material eroded from the High Buried Beach farther upstream. This mixture of pink sand and gravel is relatively unconsolidated in most cases, being reasonably penetrable until bigger gravel is reached, and it seems feasible to suggest that, at the time of deposition of the grey silty sand, a certain amount of mixing of grey and pink sediments took place. Later, as the grey deposit thickened, mixing was less.

Despite the limited area involved, the boreholes put down between Cambus and Alloa show typical buried beach sediments with their associated deposits. The presence of sub-carse peat or the buried valley of the Forth is to be expected after comparison with similar situations farther west, but the nature of the underlying gravel obviously merits further investigation. However, this is perhaps best covered below, along with the other areas of sand and gravel deposition. Here it seems more pertinent to attempt to fit the sediments into the buried beach sequence. The colour and composition of these sediments suggests that they may be equated with either the Main or Low Buried Beaches. Heights on the grey (silty) clay surface at 5.3 to 5.9 m O.D. correspond to heights on what has been described as the Low Beach between Abbey Craig and Menstrie and at East Gogar. Again, the grey clay at Cambus is very similar to that forming the Low Buried Beach near Thornhill. Despite obvious dangers in relating beach fragments over distances of as much as 20.0 km, the strong similarity between the structure of the Low Buried Beach in the west and the patch of beach deposits at Cambus suggests that they belong in the same category.

Other than the buried beach sediments, the main sub-carse deposit in the area between Stirling and Kincardine-on-Forth is sand and gravel. In a number of places, particularly near the eastern end of the area, till or even rockhead lies immediately beneath the carse-clay, but sand and gravel is by far the most common. In quantity the deposits compare with those of the Blairdrummond and Lecropt areas, but inspection shows a greater complexity in both form and distribution east of Stirling. For purposes of illustration and explanation, a division can be made between the sands and gravels that owe their morphology and distribution to fluvial deposition or erosion and those that have been effected by marine agencies. In a case such as this, where sea and river are so closely juxtaposed, no division can be absolute, but it would appear that there are areas in which one has been more important than the other. With this in mind, a line drawn across the region from north to south, near Alloa, separates an area of predominantly fluvial activity, to the west, from one of predominantly marine activity, to the east.

West of Alloa, the main source of sand and gravel is the River Devon along with the numerous streams flowing out of the Ochils. Each of these streams has its own alluvial fan as witnessed by the line of the carse edge from Airthrey in the west to Tillicoultry in the east where the carse itself merges with the fluvial deposits of the Devon. The biggest fans at Menstrie, Alva and Tillicoultry providing dry points above a wet plain have attracted the largest settlements, but almost every fan has its farm or small village. With settlement many of the streams producing the fans were artificially restricted to the one course to prevent flooding and for industrial purposes, but at times of heavy rain or melting snow in the Ochils, the streams occasionally burst their banks and spread sand and gravel over adjacent areas. Thus, the fans might be considered as still active, inasmuch as the streams have the ability to change the form of their surface, even if they do not significantly add to it. However, in the valleys behind the fans, there is gravel and sand that, under conditions of strong or high stream flow, could be carried downstream to be added to the fans and it is suggested that, without the curbs produced by settlement, they would continue to develop, if somewhat slowly and intermittently.

Although the fans are impressive features rising from the carse surface against the steep slope of the Ochils, these visible portions are, in fact, only sections of much larger features. At first sight, the fans appear to have built up on the carse surface, but this is only partly true, for while alluvial material does cover part of the carse-clay, the clay also masks the lower portions of the fans, which form an apron or piedmont of sand and gravel along the southern edge of the hills.

The relationship is well illustrated at Menstrie (Fig.V.7) where the more recent alluvium -- fine red-brown sand -- rests upon carse-clay and is often mixed with it. Away from the visible outer edge of the fan, the red-brown sand rests directly upon very coarse and tightly packed gravel. Followed in the opposite direction, towards the River Devon, these two deposits become separated by a bed of carse-clay. Between the carse and the coarse gravel, thin bands of other sediments are present, but this does not detract from the main point that a fan existed at Menstrie when the carse sea flooded into the Devon valley and continued to be built up after the deposition of the carse-clay. In addition, the mixing of sand and clay points to the probability that the two activities were at times contemporaneous.

In areas where no obvious fan exists it is still common to find gravel beneath the carse. Along the back of the carse near Powis Mains, for example, the clay often rests upon coarse brown sand or gravel (Boreholes 524, 525, 526, 530 and 531) and a similar situation has been found to exist west of Blairlogie. Where this is so, the source of the coarse material may well have been scree from the steep slopes behind the carse and in this regard it can be noted that screes are still to be found in places along the face of the Ochils. It is also possible that the conditions that led to the provision of abundant material for the fans were also conducive to the processes of mass-movement, allowing the accumulation of detritus that was later covered by carse-clay.

These two examples are repeated all along the face of the Ochils although the relationship between the clay and the gravel is best seen in the vicinity of the fans. On the Menstrie fan, thin bands of buried beach sediments are present between the carse-clay and the gravel. They have been interpreted as belonging to the High and Main Buried Beaches, the former being the older (Fig.V.7). At certain other points both hand auger and commercial boreholes have penetrated the High Beach and show that it rests upon sand and gravel (Boreholes 527, 528 and 529) providing evidence for a more accurate estimation of the relative ages of the fans and associated deposits. As well as pre-dating the carse, it can be seen that the fans were already in existence prior to the formation of the buried beaches in this area.

Near Alva a number of commercial boreholes show a stratigraphy that may be generalised as follows:-

5. Sandy clay or sand
4. Blue carse-clay
3. Sand and gravel
2. Clays and silts
1. Till

As at Menstrie, the sand and gravel shows the original development of the fan in pre-carse times while the upper sandy clay or sand indicates continued growth since. Furthermore, the difference in texture between the upper and lower deposits of the fan seems to indicate that, since the formation of the carse, the processes involved have been less vigorous and have therefore produced finer material.

The "clays and silts" that lie beneath the gravel are much more complex than this broad generalisation would suggest. In colour they vary from red to brown to grey and in consistency from "muddy silt" to "plastic clay". Considerable variations in thickness occur, but as much as 40.0 m of "clays and silts" have been recorded near Alva. In that same area, Parthasarathy and Blyth (1959) noting that they were laminated, generally free from large particles and contained arctic shells, considered these deposits to be of Late-glacial marine origin.

Near their base these clays often contain a considerable proportion of sand and are referred to as "red sandy silt" or simply "sandy clay". This may represent outwash sand poured into the sea by melting ice and in a number of boreholes the clays are separated from the basal till by sand or gravel indicating fluvioglacial activity during the retreat of the ice. Further complications are added in a few cases, by the presence of two layers of till separated by a bed of sand or gravel. It seems possible that this indicates fluctuation of the retreating ice, but the paucity of information limits the amount of interpretation that can be made.

One point that emerges from an investigation of these bore-holes concerns the formation of the Ochil fans. It has been established above that they existed prior to the formation of both the carse and the High Buried Beach, while evidence from the deep boreholes shows that they were growing soon after, or perhaps during the deposition of the Lateglacial clays, for the presence of sand or fine gravel beds mixed with mud and clay immediately below the main gravel may represent a mixing of the two deposits. Thus, it is evident that the Ochil fans are considerably older than is at first apparent.

It seems likely that the bulk of the gravel in the area west of Alloa was deposited by the Ochil streams and the River Devon. As well as providing its own material the latter may have helped to re-distribute sands and gravels by the erosion of the southern edges of some of the fans. At Menstrie, for example, the fan is limited by a buried valley of the Devon on its southern edge and the configuration of the deposit suggests that it may have suffered erosion by the river. Upstream from Menstrie, recognition of the buried valley is difficult but it may be represented by the absence of gravel from its normal position in the stratigraphy. Near the present river, a few boreholes show that gravel may be completely lacking or present only at some depth mixed with muddy sands and clays, showing the complicated sedimentation that might be expected with the flooding of such a valley.

West of Menstrie, the present Devon turns sharply southwards towards the Forth. Near East Gogar the carse adjacent to the river rests upon a gravel surface heighted at between 4.0 and 5.0 m O.D. Followed westwards, the gravel retains its relatively level surface for almost half a kilometre before dying out. Beyond that point the stratigraphy consists of muds and clays down to an altitude of -1.3 m O.D. where rockhead is encountered (Fig.V.8). Adjacent boreholes show that gravel is absent, or present only at depth, and it is suggested that the edge of the gravel surface at East Gogar marks the eastern margin of the buried valley of the Devon. The position of the western edge of the valley is not evident from the information available. However, it would seem that at some time after the deposition of the main mass of gravel the Devon followed a course that carried it farther west than at present. It must be stressed that this valley bears no relationship to that examined by Soons (1960) in the same area. The latter consisted, basically, of three glacially deepened rock basins near Menstrie, Alva and Tillicoultry, that did not bend round to meet the Forth. In contrast, the valley described here, does approach the Forth, is fluvial in origin and is obviously a much younger feature.

Although the major source of sand and gravel for this area is seen as the Devon valley and the Ochils, in the southern section, near the Forth, a possible origin is to be found west of Stirling. It would seem reasonable to suggest that the Stirling gap acted as an exit for sand and gravel from that area, if not in the form of outwash at least as material eroded from the deposits at Lecropt and Blairdrummond. It is not possible to distinguish between gravel from different sources, east or west of Stirling, but it is to be expected that material from the latter area would be found in boreholes adjacent to the present course of the Forth.

An examination of the heights at which the surface of the buried gravel is encountered near the Forth, shows a considerable variation from +2.1 m O.D. to -8.1 m O.D. However, a majority of values are grouped around O.D. At Ladysneuk, for example, close to Abbey Craig, the gravel surface is at -0.2 m O.D. while one kilometre farther east, at Manorneuk, heights between +0.4 and -0.1 m O.D. appear to be representative and farther east again, near the confluence of the Devon and the Forth, corresponding values are +0.2 and -1.0 m O.D. Although the boreholes, in which gravel is found at such heights, number only 20, they are clustered into a number of patches separated by areas where gravel is absent, or present only at some depth, and it is thought that they may be the remnants of a surface that once covered a larger area, with subsequent erosion by both the Forth and Devon producing the present distribution.

Between Cambus and Alloa, this gravel is no longer present at or around O.D., but a similar deposit forms a step beneath the landward part of the carse (Fig.V.6). This latter feature is not directly related to the former, for its surface lies at heights between 4.0 and 5.0 m O.D. forming a distinct ledge at least one kilometre long and as much as 250.0 m wide, with a cover of peat and buried beach sediments up to 2.0 m thick. In height, this ledge is very similar to the gravel surface near East Gogar, although separated from it by an area west of Cambus, where mixed clays and sands overlie rock at 3.0, 5.3 and 10.6 m O.D., gravel being absent. However, in both areas, a number of boreholes indicate that the upper few centimetres of the gravel contain a proportion of pink sand or pink silty sand. This condition has been examined at Cambus and its presence in an adjacent area suggests formation under similar conditions. Noting the similarities in height and composition it is considered that the gravel surfaces at East Gogar and Cambus represent separate parts of the same feature.

Followed eastwards the Cambus gravel is lost beneath the built-up area around Alloa. The limited number of boreholes within the town give no indication of its presence and to the east there is no re-appearance of a similar feature. Gravel is still very much part of the stratigraphy, but is does not take the same form as that to the west. Instead of having the characteristics of a sharply defined, relatively flat-topped terrace as at Cambus or East Gogar, it forms part of a sloping surface that varies in height from as low as -5.9 m O.D. near the Forth to as high as +5.0 m O.D. near the back of the carse. Furthermore, the gravel is not continuous, but interrupted by areas of till and rock that lie at heights comparable to those on the surface of the gravel. Thus, the surface is in fact a composite one, comprising areas of gravel, till and bedrock, the whole feature sloping from the inner edge of the carselands towards the present river.

The surface is almost continuous between Alloa and Kincardine, but is modified slightly near Kennetpans where an embayment occurs and the stratigraphy includes no gravel, only clays of silty sands resting upon rockhead at -10.1 m O.D. Near Kincardine, the feature is well developed in gravel, till and rock (Fig.V.9) while in the vicinity of Clackmannan, rock with small amounts of gravel, is the main component (Fig.V.10). Throughout the area the gravel varies in thickness from 0.2 m to a maximum of 8.7 m but in most boreholes it is little more than a metre thick. In addition there is no well marked pattern as far as the distribution of these figures is concerned, adjacent boreholes showing variations of as much as a metre, but in general, the gravel appears to thin out towards the inner edge of the feature and may be completely absent at the back where its place is taken by rock or till. This pattern is broken near Kilbagie where sample gravel thicknesses at the back of the feature are 2.1, 2.7 and 3.0 m while to the south of this in the Kincardine area, figures of less than one metre are common and minima of 0.2 and 0.3 m have been recorded. Apart from this the original generalization appears to hold true.

A feature, similar in terms of height, form and composition, to that described above, has been reported in an area between Grangemouth and Airth on the south side of the Forth (Sissons, 1966, 1969). Although the northern portion is somewhat smaller than that to the south, both have a number of characteristics in common. The height range encountered in both cases is between +6.0 and -6.0 m O.D. with only occasional values outside this and most clustered around O.D. As well as height range, height distribution is also similar, so that each feature rises from its lowest points near the present River Forth to its highest beneath the northern or southern limits of the carselands, as the case may be. Turning to the composition of the surface, the comparison can be followed through, with the gravel layer, planated rock and planated till present on both sides in similar situations. On the southern side of the Forth, however, the gravel appears to be more extensive. The gravel may rest upon each of the other elements making up the surface, but more commonly it overlies deposits referred to in the borehole logs as red, brownish-red or brown clay and interpreted as Lateglacial marine clays. Taking this evidence into consideration, it seems certain that both surfaces were formed contemporaneously and under the same conditions.

Sissons has interpreted the gravel layer as representative of a period of marine erosion during which rock and till were planated while the gravel layer itself was built up from material eroded from the till and other superficial deposits along the shoreline (Chapter I). A marine formation was supported by a number of factors including the form of the feature, the presence of planated rock and till, the truncation of the underlying Lateglacial clays, the incorporation of shells in the gravel layer and the existence of marine cliff-forms at a number of places along the landward margin of the surface. The first three pieces of evidence also apply to the feature on the northern side of the Forth. However, neither shelly gravel or cliff-forms are common. Near Clackmannan, shell fragments have been found resting upon planated rock, but it is possible that they are associated with the carse sea rather than with an earlier sea-level. In the case of the cliffs, two factors might explain their absence. The main cliffs on the south side of the Forth are cut into the sediments of the raised beaches associated with the Perth Readvance. In contrast, similar sediments are not present along the inner margin of the buried gravel layer to the north, for the latter lies mainly within the limits of the readvance (Sissons and Smith, 1965a) and for the most part the gravel merely thins out against the rising rock surface. Where the cliff has been cut in solid rock as it has south of Hill of Airth, Sissons sees ice accomplishing the original erosion of the rock with marine activity later producing some modification. Along the north shore, glacial action can be seen in the moulded form of the landscape along the back of the carse but the sea that produced the buried gravel layer does not appear to have taken advantage of any steepening of the shore. At most the sea appears to have eroded till veneering the glaciated surface, incorporating the constituents in the gravel layer.

Looking at the general configuration of the landscape around Kincardine, Grangemouth and Falkirk where the main development of the gravel layer occurs, it can be seen that the greatest exposure is to the east and north-east out over the waters of the widening Firth of Forth. An increased frequency of easterly or north-easterly winds at some time in the past may well have been instrumental in producing the erosion associated with the formation of the buried gravel layer. In such a situation, the relatively sheltered nature of the shoreline between Kincardine and Alloa would have limited cliff development and restricted the extent of the gravel on the northern side of the Forth.

In the Grangemouth-Falkirk-Airth area, Sissons (1969) was able to deduce the age of the buried gravel from its relationship to adjacent sediments. It could be shown to be younger than the Perth Readvance since it extended into the area covered by ice at that time and since its formation was accompanied by erosion of deposits associated with the readvance. Both facts apply north of the Forth also, but without the cliffing of the Perth Beach sediments in the second case. The other event used by Sissons to establish the age of the gravel was the formation of the Main and Low Buried Beaches, both of which overlie the gravel layer in parts of the area. Using this information it could be shown that the buried gravel came into being some time after the Perth Readvance but prior to the formation of the buried beaches. On the northern side of the Forth, the latter are not conspicuous and appear to be present only as isolated patches of fine grey sand, that do rest upon the gravel where they are encountered. Thus it is assumed that the bracketing dates established for the gravel south of the Forth also apply north of the river.

Followed westwards beyond Alloa it is suggested that the gravel layer may be equated with the patches of gravel lying close to the present course of the Forth as far west as Stirling. With altitudes close to O.D. corresponding to heights on the buried gravel in the Kincardine area, it is thought that they indicate its westward extension up the Forth valley. The gravel surfaces at East Gogar and Cambus also compare in terms of height with the higher parts of the buried surface farther east. However, at neither of these places in the west does there appear to be a direct link between the higher and lower gravels. It is considered that the surfaces at East Gogar and Cambus, although perhaps not unaffected by the presence of the gravel sea, are essentially depositional in origin, the constituent materials being provided by the Forth and the Devon as well as certain local streams.

Finally it should be noted that close to the Forth boreholes often show a stratigraphy that is rather complicated and inexplicable in terms of the features indicated above. The same is true of the Devon where a hand bore was put down for over 8.0 m through soft layers of clay, silt and sand without encountering buried beach or buried gravel deposits. It is thought that this indicates the presence of buried valleys beneath the main rivers, similar to those discovered west of Stirling.

Conclusion

In the area between Stirling and Kincardine the sub-carse deposits are notable for their variety and complexity. The following elements have been identified.

1. The High Buried Raised Beach, lying beneath the northernmost part of the carselands between Abbey Craig and Menstrie. In this area, the beach is composed of pink silty sand and clay with a layer of soft peat normally covering its surface. Heights along the former shoreline vary between 10.7 and 7.9 m O.D. while along the southern edge of the feature values as low as 7.3 m O.D. have been recorded.
2. The Main Buried Raised Beach, resting upon the eroded southern edge of the High Beach. Grey silty sand is the main constituent of the beach which supports a thin and variable cover of peat. Heights on the surface of this feature fall within the range 6.6-7.7 m O.D.
3. The Low Buried Raised Beach, present along the edge of the Main Beach and in a very limited area near Cambus. In both places it is composed of grey (silty) clay resting upon grey silty sand, but at Cambus the clay cover is thicker and more uniform. Measurements on the surface of the feature show that it varies in altitude between 5.7 and 6.8 m O.D. south of the Main Beach and between 4.5 and 5.9 m O.D. at Cambus. As in the case of the other beaches, the Low Beach is overlain by a bed of peat.
4. The alluvial fans built up along the southern edge of the Ochils. Some of the sediments forming these features rest upon the carse, but the bulk of the sediments can be followed beneath it and also

beneath the buried beach sediments indicating the relative ages of these features. The streams forming the fans, in combination with the Forth and Devon appear to have been mainly responsible for the widespread distribution of gravel in this area, from Alloa westwards.

5. The Buried gravel layer and accompanying planated till and rock. This feature is best developed between Alloa and Kincardine with a possible westward extension almost as far as Stirling. Its surface slopes with varying steepness from its back edge towards the Forth, producing a height range of +5.0 to -6.0 m O.D.
6. The buried valleys of the Forth and Devon. Although not nearly so well developed as those farther west, they form significant elements of the sub-carse morphology in certain areas. The valley of the Devon joins that of the Forth a short distance west of the confluence of the present streams.

CHAPTER VI

RESULTS OF THE LABORATORY ANALYSIS OF SELECTED SAMPLES

As noted in Chapter II, sediment samples were collected at various localities between the Lake of Menteith and Kincardine-on-Forth and subjected to laboratory analysis. Initially, 93 samples were examined, allowing a sample/borehole ratio of 1 to 7. Of these samples, 72, comprising both carse and sub-carse deposits as well as gravels and recent fluvial sediments were selected for additional analysis. Buried peat was also collected for special examination.

Due to the empirical method of selection, the sample sites were not uniformly distributed throughout the area and this had certain repercussions in terms of the proportions of the various sediments in the total sample. As a result of this and partly due to the overall distribution of the various sub-carse deposits, the number of samples of each sediment type was not the same. Being the most widely distributed, grey silty sand accounted for the largest proportion of the samples with a total of 22, while the remainder were almost equally divided between carse-clay, pink silty sand, grey silty clay and the other sediments noted above. Finally, certain limitations were imposed by the shallow sampling of the buried beach sediments, the small sample size and the possible contamination of the samples. These problems have been outlined in

Chapter II and can be considered to apply to all sub-carse deposits.

As a beginning, three methods of analysis were considered useful for the present investigation. Firstly, measurements of the hydrogen ion concentration or pH of the deposits were taken in an attempt to obtain some insight into their formation. This relatively simple method of showing the degree of acidity or alkalinity of sediments was chosen as a means of examining their supposed marine origin, on the premise that, in the area concerned, marine deposits should produce readings tending more towards the alkaline end of the scale than fluvial or other deposits.

Secondly, mechanical analysis was carried out on the samples to determine the proportions of sand, silt and clay in each. From field inspection, it had been noted that the various sub-carse deposits were normally distinguishable by their texture, and mechanical analysis was in part a means of quantifying this. In addition, it was considered that the results could be used in conjunction with the stratigraphy and distribution of the sediments to give some information on their origin.

Thirdly, each sample was to be analysed for organic carbon content. The carse-clay often contains organic material distributed in lenses or fragments throughout its thickness. Compared with this, the sub-carse deposits with few exceptions are not obviously organic, but to examine the possibility of fine organic material being well mixed with the deposits, a number of samples were chosen for pilot experiments. From 24 tests carried out using an EEL colorimeter to estimate the percentage of carbon present (Chapter II) only 7 showed values greater than 1%, the highest being 2.4%. For the tests a representative cross-section of samples was used, including sub-carse sediments, carse-clay and recent river alluvium, but the final results produced no obvious pattern apart from generally low values throughout. Even the carse-clay proved low in organic carbon although vegetable matter and shell fragments are often associated with it. However, it is thought that this anomaly may be explained by the organic material being concentrated in lenses or bands rather than distributed throughout the clay.

Sub-carse deposits accounted for 5 of the 7 samples with more than 1% carbon but a further 10 were well below this figure and it was considered that the higher values were not representative of the deposits as a whole but, due to contamination of the sediments by the buried peat layer or due to rootlets from this layer passing down into the sub-carse deposits. As a result of these preliminary tests, it was considered that the amount of organic material in the buried beach sediments was too low to merit further investigation. Therefore no additional tests of this type were carried out, this decision also being influenced by the difficulty of ensuring uncontaminated samples.

Thus, laboratory work on the sediments consisted mainly of the determination of pH and mechanical analysis. In addition, an attempt was made to examine the buried peat layer for pollen content in a few localities, while the end-products of mechanical analysis were treated for heavy mineral determination. In the following paragraphs, the results of these experiments will be presented and explained.

Determination of pH.

The samples used in this experiment fell into four broad groups. These consisted of the three different sediment types associated with the High, Main and Low Buried Raised Beaches together with the carse-clay. In general the average pH values in each group show them to be moderately or only slightly acid with individual samples ranging from strongly acid to weakly alkaline.

The highest value was produced by the pink silty sand of the High Buried Beach with no individual result below a pH of 5.8 and an overall mean of 6.6 indicating very slight acidity. Closest to this among the sub-carse sediments was the grey silty sand with an average pH of 6.2, concealing a range of values between 4.7 and 7.4. In this case, the three lowest results were found in sediments obtained from beneath Flanders Moss, but, apart from this, there is no obvious pattern to the distribution of the pH values. The most acid of the deposits proved to be the grey silty clay of the Low Beach, giving a spread of results between 4.5 and 6.8 with a mean of 5.6. In addition pH measurement of the carse-clay samples gave indications of slight acidity overall with a mean of 6.3 and a relatively small range between 5.1 and 7.2. The above, and other relevant information on pH determination, is brought together in Table VI.I.

Although these experiments are relatively simple and provide results that are to some extent to be expected, they do require some discussion or explanation. It has been recognised for some time that the carse-clay is of marine origin (Chapter I) and the work of Sissons (1966) and Newey (1966) has indicated a similar formation for the sub-carse deposits examined here. Since the salinity of sea-water produces a high pH of the order of 7.5 to 8.0 (Strickland and Parsons, 1968) it might be expected that sediments laid down in a

TABLE VI.I

Measurement of pH

	Number of Samples	Maximum pH	Minimum pH	Mean
High Buried Beach	8	7.4	5.8	6.6
Main Buried Beach	26	7.4	4.7	6.2
Low Buried Beach	10	6.8	4.5	5.6
Carse-clay	12	7.2	5.1	6.3

N.B. The carse-clay samples were collected at depths greater than 1.0 m, to escape the effects of agricultural activity.

marine environment would show values similar or close to this. Some of the results quoted here approach the lower end of this scale but the majority show at least slight acidity. However, several points can be put forward in explanation of this.

In the first place, it is considered that during the formation of the buried beaches, and the carse, sedimentation was taking place in a modified marine environment. The introduction of fresh water at the head of the Forth estuary would have the effect of reducing the salinity and the pH of the water, the latter being aided by the fact that the fresh water originated mainly on the relatively acid rocks of the Highlands. In the case of the High Buried Beach, formed according to Sissons (1966) when ice was present and melting in the upper Forth valley, large quantities of fresh water must have been present, yet for some reason it has produced the highest average pH of any of the beaches. It would seem likely that even when the buried beach and carse sediments were first laid down, their pH values were lower than normal in marine deposits due to their estuarine location.

Once the sediments had been deposited they were exposed and vegetation grew over their surface as indicated by the buried peat layer in the case of the buried beaches. Holmes (1966) notes that the pH of moss peat may be as low as 2.8 to 3.7 and, in the present study, measurements made on a lense of peat enclosed in carse-clay gave values of 2.5 and 2.6. As the peat grew, percolation of acidulated water into the underlying sediments would have the effect of increasing their acidity. The leaching of salts from the upper layers of the exposed deposits would have similar results. Again the deposits of the High Beach are anomalous in that they show what appears to be strong physical evidence of leaching in the grey surface layer, yet the pH values remain comparatively high. Compared with this, low results in other deposits may represent leaching. Parthasarathy (1954) saw leaching as responsible for certain low salinity readings in the Devon valley carse-clay and this may be reflected in other areas in low pH values. Five samples taken from within a metre of the carse surface gave results ranging from pH 3.8 to 4.5 while samples from greater depths normally gave pH values greater than 5.0. The carse, however, unlike the buried sediments, has undergone agricultural interference of various forms and this has undoubtedly affected it chemically, especially in the surface layers.

Taking the above factors into account, it is perhaps somewhat surprising that the pH values have remained as high as they have. It is suggested that they are still sufficiently high to indicate a possible marine origin for the buried beach deposits. Although not sufficiently strong in themselves to prove such an origin, the pH experimental results add to the pollen and topographical evidence (Newey, 1966; Sissons, 1966) and provide at least some contribution towards the conclusive proof of a marine origin for the sub-carse sediments.

Particle Size Analysis.

The results of particle size analysis carried out on the buried beach and carse sediments (Fig.VI.1) are based on a total of 72 samples examined using a combination of hydrometer analysis and sieving techniques (Chapter II). During the collection of the

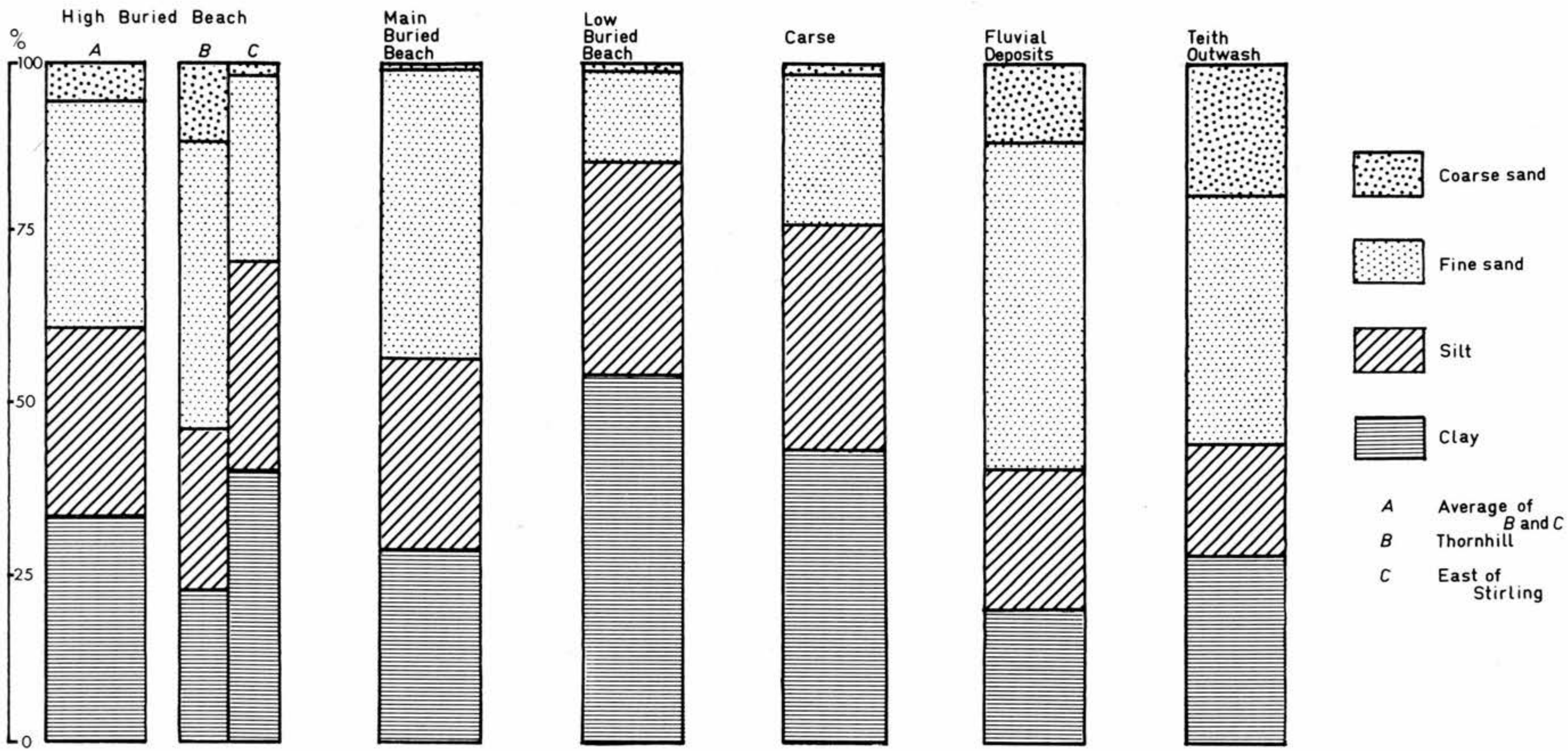


Figure VI.1 Average composition of buried beach and associated deposits samples, and during preparation for analysis, it became increasingly obvious that very fine deposits were being dealt with. For example, it is normal to sieve air-dried samples initially through a 2.0 mm mesh, retaining the sub-2.0 mm fraction for mechanical or chemical analysis and discarding the remainder after weighing. With both buried beach sediments and carse-clay, no sample was found to contain measurable quantities of material larger than 2.0 mm in diameter. According to the size scale used (Table VI.II) this meant that in none of the deposits were there particles present with equivalent diameters greater than those found in coarse sand and in fact only a few samples contained a proportion of that fraction.

TABLE VI.II

Equivalent Particle Size Diameter (in millimetres)

	2.0-0.2 :	0.2-0.02 :	0.02-0.002 :	Below 0.002
Fraction:	Coarse sand	Fine sand	Silt	Clay

(After Russell, 1966)

The deposits of the High Buried Beach were analysed for particle size at eight locations, three of which lay in the vicinity of the village of Thornhill and five close to the Ochil Hills, east of Stirling. The results of analysis gave the proportions of the various size fractions at each location and from this the average composition was calculated. Following the scale outlined in Table VI.II, this showed that the deposits of the High Beach contain on average, 5.5% of coarse sand, 33.0% of fine sand, 27.9% of silt and 33.6% of clay.

Despite the limited sample size, certain overall characteristics, as well as individual variations, could be seen. In his work on the south side of the Forth, Sissons (1967a) has referred to the sediments of the High Buried Beach as "pinkish silty sand" and the same term has been used in the present study. On consideration of the average figures, it can be seen that the sand and silt fractions together account for 66.4% of the total, apparently confirming the use of the term "silty sand". However, a combination of the silt and clay percentages gives a figure of 61.5% suggesting that, in some cases the deposits are as much "silty clay" as "silty sand". Further illustration of this can be seen in the mean composition of the Thornhill and Stirling groups. In the former, the sands and silt provide 77.5% of the total compared with the 46.0% of the silt-clay combination, while east of Stirling sands and silt together make up only 59.8% of the whole, silt and clay accounting for 70.8%. Thus in the western part of the area under study, the High Buried Beach is composed of measurably coarser material than the corresponding feature in the east.

The limited number of samples examined from the High Beach deposits restricts the conclusions that can be made. However, when viewed in conjunction with field observation there is a degree of correlation between the visual evidence of texture and the laboratory results. It was noted above that the sediments of the High Buried Beach between the Lake of Menteith and Blairdrummond appeared relatively coarse when examined initially in the field (Chapter III) and this is confirmed in the mechanical analysis figure of 11.7% for the coarse sand fraction. In contrast, east of Stirling, the deposits have a higher clay content (Chapter V) as is evident from the percentage of that fraction revealed by laboratory analysis. In this latter case, the results are probably somewhat misleading, for there are areas in the High Beach along the edge of the Ochil Hills where the deposit is visibly coarse. Overall, the distinction between the two areas may be related to the environment in which sedimentation took place and this will be pursued further, below (Chapter VII).

In the same way, mechanical analysis tests were carried out on 20 samples collected from the deposits of the Main Buried Raised Beach. An average for all 20 samples was calculated and this gave values of 0.5% coarse sand, 43.3% fine sand, 27.7% silt and 28.5% clay, which would appear to be in agreement with the term "silty sand" commonly used for the Main Beach sediments. In some cases the term "fine sand" has been used for descriptive purposes and this is reflected in the relatively high figure for fine sand obtained from analysis. Indeed, the average masks some very high individual values in the fine sand fraction, nine of which exceed 50.0% with an absolute high of 65.3%.

The typically fine texture of the deposit is also indicated by the small percentage of coarse sand encountered. Only eight samples contained that fraction at all and then only in very limited quantities. With only one exception the coarser material was limited to samples collected west of Stirling and on closer inspection a definite pattern could be seen. Five of the samples were collected close to the junction of the Main Beach and the Teith sands and gravels while one of the others was sufficiently close to the buried valley of the Goodie Water to have obtained coarser sediments from that source.

Elsewhere, both east and west, coarse sand is atypical of the deposit as a whole.

The mechanical composition of the third of the buried features, the Low Beach, was examined in ten samples. The deposits of this feature are easily recognized in the field as being rather finer in texture than those of the higher features and this is borne out in the analysis. Some problems arose during the experimental work apparently because of the fine nature of the Low Beach sediments. It was found that the hydrometer floated at very high levels in the suspension, perhaps due to the slow rate of fall of the fine clay particles. As a result, the cumulative percentage, from which the final composition was measured (Chapter II), did not correspond to the results obtained by sieving. In a number of experiments, the highest cumulative percentage measured by hydrometer analysis proved to be 10-20% higher than the lowest percentage obtained by sieving (whereas the former should have been the lower of the two), the exact difference depending upon the diameter of the sediment particles involved at each stage. The exact cause of this disparity could not be determined, but experiments showed that, especially with the finer sediments, an original trial sample of greater than 30.0 gms in weight reduced the possibility of the above occurrence.

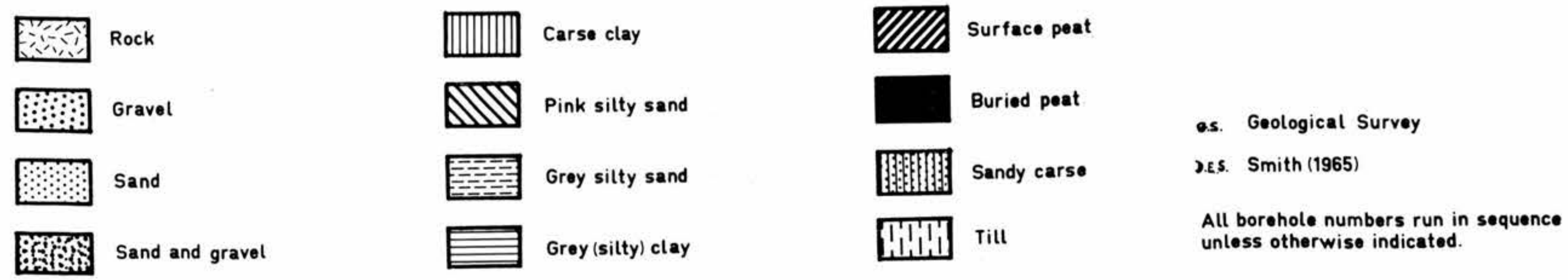
Analysis of the deposits of the Low Buried Raised Beach showed that on average they contained 1.0% coarse sand, 13.7% fine sand, 31.2% silt and 54.1% clay. Despite the presence of the coarse sand, with a value greater than that for supposedly coarser Main Buried Beach, the most obvious factor is the high percentages of silt and clay. Together they comprise over 85% of the total. As with all average figures the extremes are lost and in this case the latter are perhaps more interesting than the former. Of the ten samples examined, three gave silt-clay combinations greater than 90% with a maximum of 98% in two of these three. Only two of the remainder fell below 80% and in one sample, the proportion of clay alone stood at 81%. Despite the limited number of samples used the extremely fine texture of the deposits of the Low Beach is rather obvious and characteristic of the feature.

Having considered each of the buried beaches in turn, in terms of their mechanical composition, they can now be compared both in terms of average results and also in terms of results from individual samples. To facilitate this, each sample was plotted on triangular graph paper in terms of its clay, silt and sand content. Where a sample contained both fine and coarse sand fractions, these were taken together for representation on the graphs. The final results are presented in Figure VI.2.

In the first place the values obtained for average composition were plotted and these show the general location of each group with a broad indication of the relationship between them. The most obvious features of this graph (Fig.VI.2a) are the close proximity of the High and Main Buried Beach deposits and their separation from the average plot for the Low Beach samples. It can be seen that the main differences lie in the sand and clay fractions. All three are similar in terms of their silt content, but the Main and High Buried Beaches have approximately 20% more sand than the Low Beach while in the latter the difference is made up by a similar percentage increase in the clay fraction.

THE SUPERFICIAL DEPOSITS OF THE AREA BETWEEN—
—STIRLING AND KINCARDINE-ON-FORTH

(The location of each section is indicated in Figure V.1.)



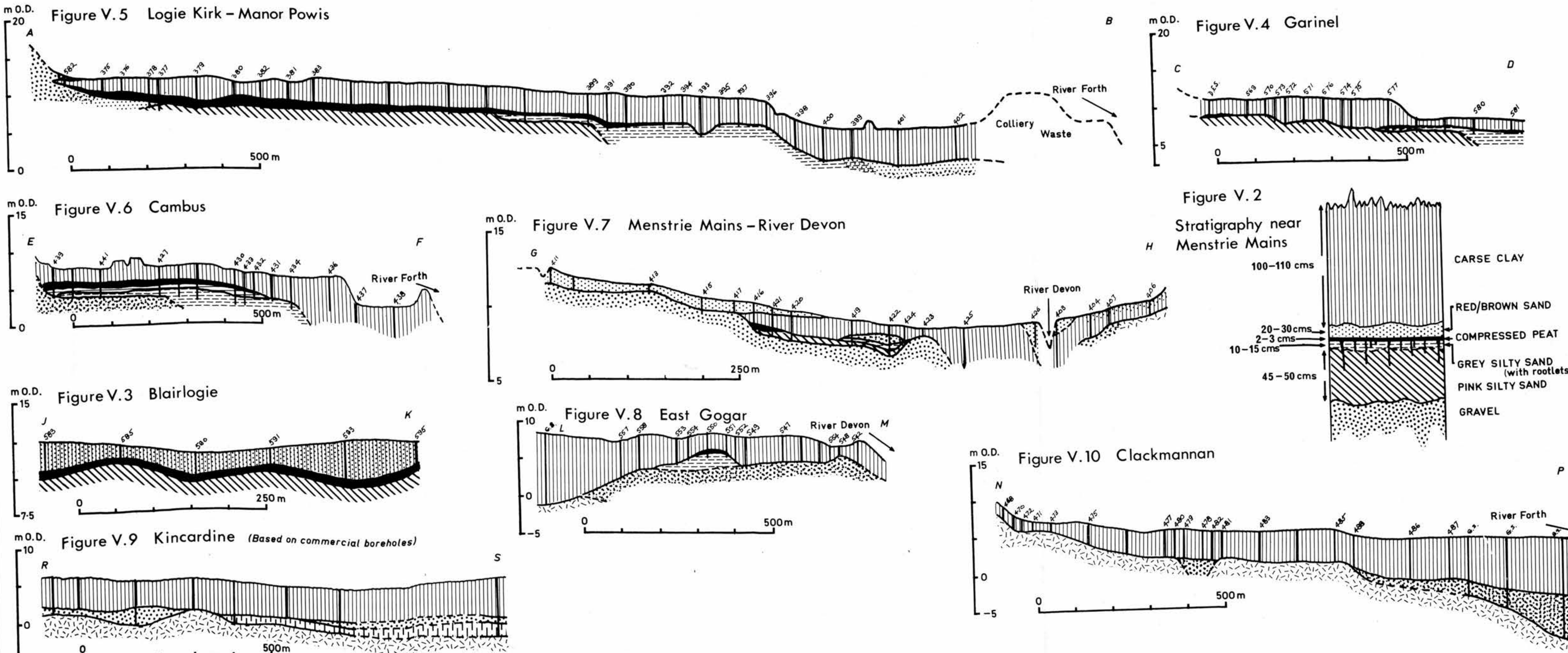
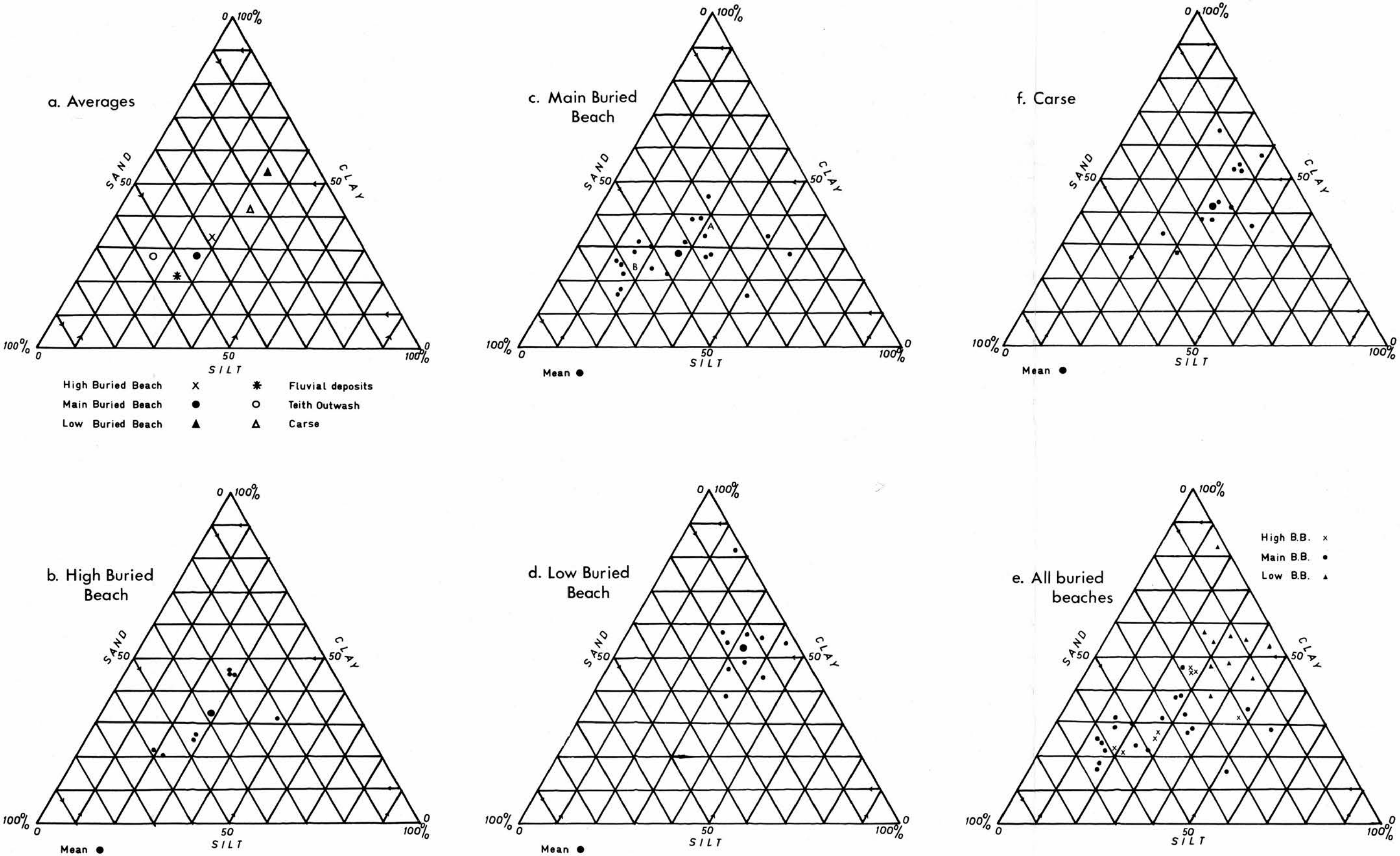


Figure VI.2 Results of particle size analysis



For comparison, the mean composition of a number of deposits associated with the buried beaches has been calculated and plotted on the graph. These include carse-clay (13 samples), recent deposits of the River Forth or Teith (6 samples) and the finer sediments of the buried outwash fan at Blairdrummond (5 samples). As can be seen, the carse-clay is more akin to the deposits of the Low Buried Beach than to the others, a fact that was often apparent in the field, where the main difference between the two often appeared to be one of colour alone. However, in certain areas, the mixing of carse-clay with coarser fluvial deposits produced the variety already noted (Chapters III, IV and V). With both the river sediments and those of the buried fan, the average plot shows a composition somewhat coarser than any of the buried beaches.

All points mentioned thus far refer only to average conditions and closer examination shows considerable variation from the mean in a number of cases.

Despite the limited number of samples of High Beach material, the graph (Fig.VI.2b) does indicate a division into two groups dependent upon differences in the clay and sand fractions, the silt content being similar in both cases. On examination of the location of the samples involved, it was found that the groups were mainly a graphical indication of the textural differences in the beach between Thornhill and the area east of Stirling.

On the graph showing the composition of the Main Buried Beach (Fig.VI.2c) a division into two main groups can be made also, although the distinction is not so clear as with the High Beach. One set of points (A) indicates a rough balance between sand, silt and clay, while in the other (B) the sand shows a definite increase at the expense of the silt. Unlike the High Beach there is no obvious relationship between location in the field and position in one or other of the groups. However, if a distinction is made between coarse and fine sand, deposits with a proportion of the former are commonly linked with the area west of Stirling. This brings out one of the drawbacks of the system of graphical representation in which coarse and fine sand are taken together. Considering Figures VI.2b and VI.2c it can be seen that five of the Main Beach samples have greater proportions of sand than the sandiest of the High Beach samples suggesting that the former is the coarser of the two. None-theless, a breakdown into coarse and fine fractions shows that in absolute terms the High Buried Beach, with its 5.5% of coarse sand, is the coarser.

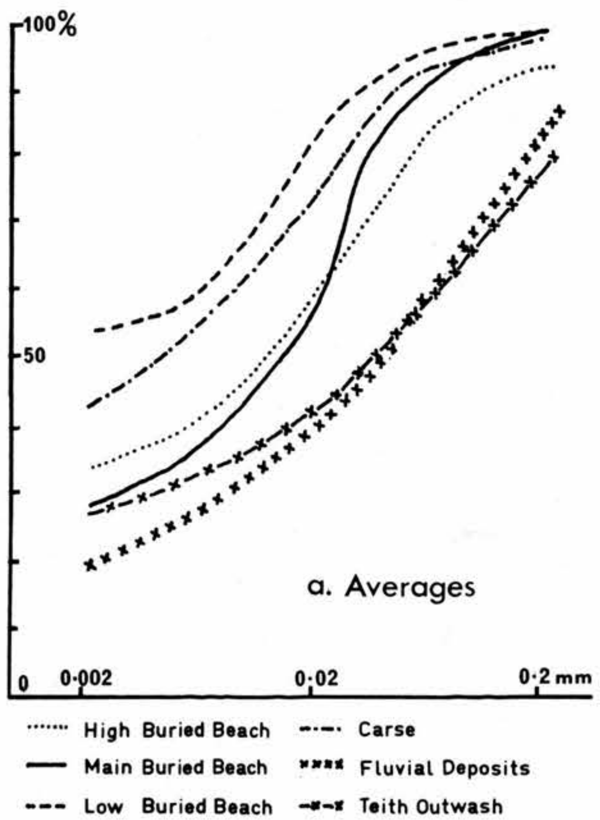
The fine nature of the deposits of the Low Buried Raised Beach is apparent in Figure VI.2d. Nine of the ten samples examined contain more than 40% clay and all but one lie within the range 40-60% clay. That which shows 81% clay is well separated from the remainder which form a distinct grouping. The sediments of the Low Buried Beach tend to be more homogeneous than those of the other beaches as may be seen when all are plotted graphically. With only ten samples chosen, it is possible that the results may not be representative of the feature as a whole, but, bearing in mind the method of collection, the extent of the feature and the nature of the field evidence, it is suggested that the homogeneity mentioned above is real and not produced solely by chance.

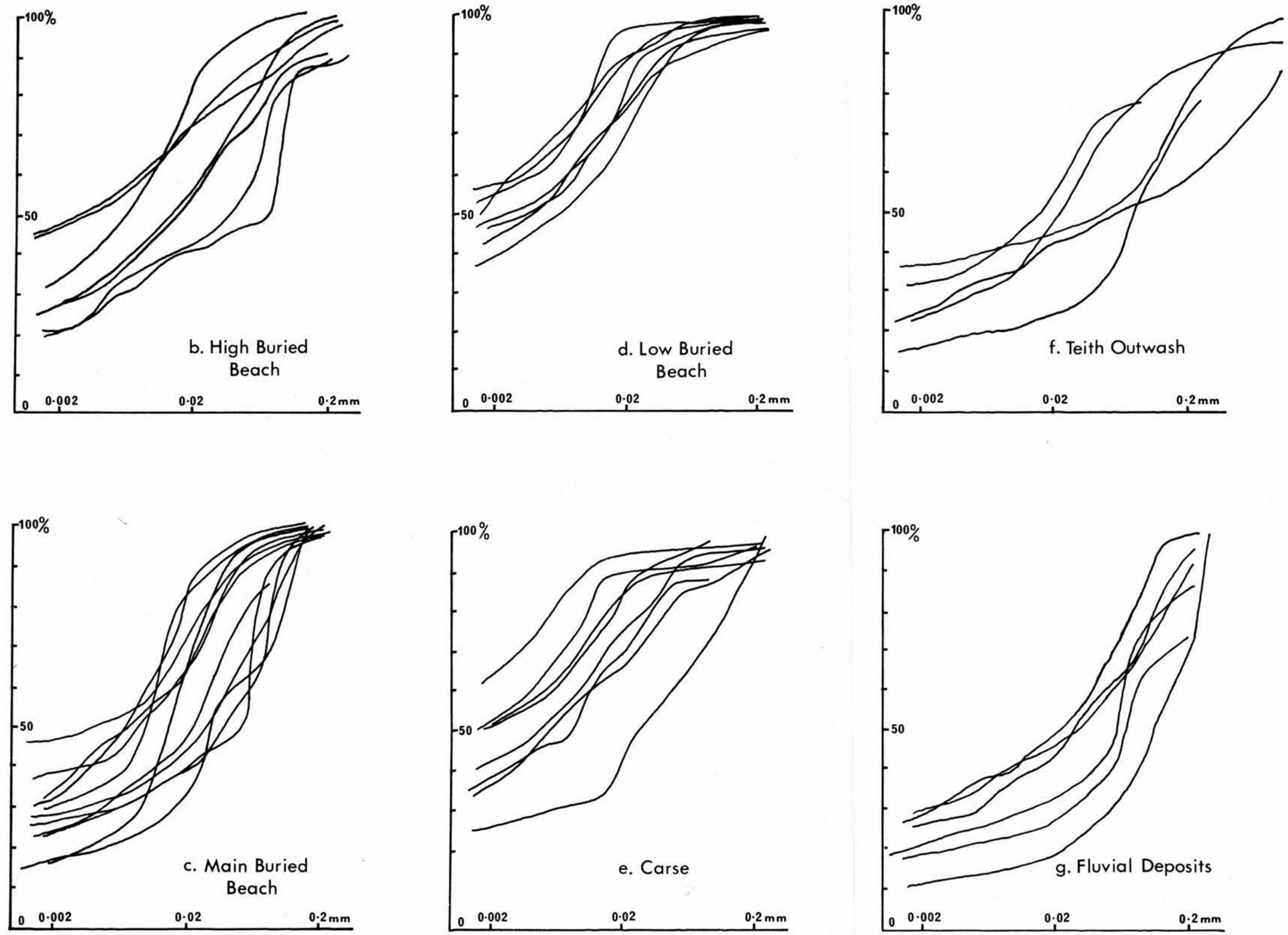
As a final summary of the information obtained from mechanical analysis, Figure VI.2e was drawn to show the limits within which the various deposits were normally located and their relationship to each other.

In addition to comparing the deposits in terms of the different particle size fractions that they contain, some comment must be made concerning the shape of the distribution curves from which the results were obtained. These are reproduced in Figure VI.3. Within the graphs for particular deposits there are variations in the positions of individual curves, but in most cases there is a reasonable similarity in shape, probably most marked in the curves for the Main and Low Beaches. The greatest variety in curve shape is to be found in the samples for the buried fan at Blairdrummond and this may have been produced by the interplay of different geomorphological processes. Most of the samples, for example, were obtained close to the outer edge of the fan where both marine and fluvial processes were probably active.

To facilitate comparison between deposits, average curves were produced (Fig.VI.3a) and they show that the three lines for the buried beaches and that for the carse-clay are strongly related with regard to their shape. All are characterised by a convex curve at the coarse end of the scale with a concave curve at the fine end. At the same time all four of these curves differ from the overall gentle concavity of those representing the recent fluvial deposits and the buried fan at Blairdrummond. Doeglas (1946) has shown that there is a relationship between the shape of the mechanical analysis distribution curve and the environment in which sediments are deposited. Although it was not possible to compare the curves in the present study with those of

Figure VI.3 Particle size analysis
(Curves of cumulative percentage against grain size)





the earlier work, due to variations in recording methods, it is considered that this basic conclusion will still hold true. It would therefore appear reasonable to infer that the carse-clay and the three buried beaches originated in similar environments. Since the marine, or marine-estuarine, origin of the carse-clay is well established the same would apply to the other features, supporting the marine formation already indicated by Sissons (1966) and Newey (1966). In the same way, the correspondence between the curves for the recent fluvial sediments and the buried fan suggests a similar origin, although in this case the variability in the individual curves of the latter, mentioned above, limits the emphasis that may be put on this particular relationship.

Two main points emerge from the results of mechanical analysis. Firstly, after considering the sediment types contained in the buried beaches and the carse, it can be seen that each feature is characterised by a particular combination of the various size fractions. In this way the features can be seen to differ. Secondly, mechanical analysis points to a mode of formation common to each of the buried beaches and the carse-clay.

Heavy Mineral Analysis.

A by-product of the method of particle-size analysis used above, is the separation and collection of the fine sand fraction of the sample. Due to the broad range of minerals commonly found in this fraction, it is frequently used for the examination of the heavy mineral content of sediments. By a process involving flotation, centrifuging and filtering, as explained in Chapter II, the heavy minerals are isolated before being mounted in an immersion oil and systematically identified with the aid of a polarising microscope. Identification is normally accomplished by reference to certain mineralogical properties, such as colour, shape, cleavage or refractive index, but in the present study the minerals were examined mainly by comparison with reference books or specimen slides.

By the study of the heavy mineral content of certain sediments it was hoped to obtain an insight into the source of the materials that now form the buried beaches and the carse. With this in mind, four samples were prepared, including one from each of the buried beaches and one from the carse-clay. In each case, 100-150 minerals were identified and the proportions of individual types were expressed as a percentage of the total.

The sample obtained from the High Buried Beach showed that the minerals of the garnet group were most common with 47% of the total, closely followed by zircon with 41%. The only other minerals in any quantity were chlorite and hornblende with slightly over 5% each. It should be pointed out that the minerals of the iron group were not counted although their presence in fairly large proportions was noted. In terms of origin the iron minerals were probably supplied by the weathering and erosion of Old Red Sandstone rocks, as was the zircon (Waterston, 1965) while the minerals of the garnet group were probably the result of the breakdown of schistose Highland rocks.

The sample for the Main Beach sediments showed certain similarities to that of the High Beach. The percentages of garnet and zircon were still relatively high with 37% and 25% respectively. However, both chlorite and hornblende showed higher values (over 10% each), while traces of augite, enstatite and tourmaline were also recognised. Again, the minerals of the garnet group may well be an end-product of the decomposition of Highland rocks or possibly, to a lesser extent, the result of the erosion of the High Beach. Similar reasoning might apply to the zircon grains. In some areas it was noted that the silty sand of the Main Beach took on a greenish colour and it is suggested that this was due to increased chlorite content. It should also be noted that on examination in the field, the silty sand often had a shiny or silvery appearance and this was explained as due to the mica content of the deposit. During flotation for the separation of heavy and light minerals large quantities of muscovite were floated off as light minerals. Both biotite and chlorite would help to produce the shiny nature of the deposit, also, but it seems likely that the muscovite would be most important in this respect. It is therefore considered valid to refer to the deposits of the Main Buried Beach, in certain areas, as "micaceous silty sand".

The sediments of the Low Beach were also found to be extremely rich in mica. In the sample examined, chlorite and biotite together made up over 90% of the total with only traces of other minerals such as garnet, hornblende and augite. It is likely that the sample used was not completely representative of the beach as a whole, but it does suggest an origin in the schistose rocks of the Highland area west of the Lake of Menteith.

By examining the heavy minerals it was considered that it might be possible to note an increased content of minerals of Highland origin from the High Beach through to the Low, bearing in mind the position of the ice front at the time of formation of the former

(Sissons, 1966). Although this may be represented by the decrease in the zircon percentages and the rise in the mica group, the evidence cannot be entirely conclusive due to the low number of samples used.

As a final step, a carse-clay sample was prepared and the heavy mineral content measured. In this case, a relatively wide range of minerals was obtained, as might be expected from consideration of the age and stratigraphical position of the carse. With 43% of the total, chlorite stood well ahead of garnet and zircon with 18% and 17% respectively. Hornblende, augite and enstatite showed values between 5-10% while traces of tourmaline, epidote, biotite and possibly staurolite were also recorded. The high chlorite content was regarded as a reflection of the clayey nature of the deposit while the greater range of minerals encountered was perhaps related to the greater extent of the carse, compared with the buried beaches, allowing the incorporation of minerals from a wider area. It has to be allowed, however, that this may be a result of the location of the particular sample used and this does apply to all the samples examined here. Thus the results of heavy mineral analysis can only give a picture of the conditions at four specific points in a rather large area.

Pollen Analysis.

Both the Main and Low Buried Beaches have been examined for pollen content in their upper layers and in the peat deposits immediately overlying them (Newey, 1966). Although this work took place on the south side of the Forth, it was considered that the findings would generally apply to the north side of the river also

(Chapter I). However, an attempt was made to analyse pollen from the upper layers of the High Beach and from the overlying peat. Five slides were prepared, three from one site at Powis Mains (NS 8191 9601) and two from a site at Wester Kerse (NN 6526 0001), the material being obtained from the junction between the beach surface and the overlying peat or from the lowest layers of the peat. Four of the slides contained little pollen and were unsuitable for analysis, the fifth was examined and analysed by W.W. Newey. It was obtained from the lowest 2.0 cm of peat resting directly on the beach surface at Wester Kerse, near Thornhill.

Of the arboreal pollens, *Betula* proved to be most abundant with almost half of the 95 arboreal grains counted. The remainder were divided almost equally between *Corylus* and *Salix* with a few grains each of *Pinus*, *Alnus*, *Ulmus* and *Quercus*. Of the non-arboreal group, the spores of *Sphagnum* were by far the most common and there was no evidence here of the salt-marsh vegetation found at the junction of the buried peat and the deposits of the Main and Low Beaches to the south of the Forth (Newey, 1966). Considering the relative proportions of the different pollens, Newey came to the conclusion that the peat had been forming during Zone V of the pollen sequence. Indicating this was the prevalence of *Betula* pollen with *Corylus* of secondary importance. The pollen grains of *Ulmus* may represent the first signs of the climatic improvements that took place in Zone VI and, although small in number, they suggest that the formation of the accompanying peat took place in the latter part of Zone V, since Newey (1965) has shown that *Ulmus* began to appear only then in south-east Scotland.

The relative abundance of *Salix* in the analysis was thought to be due to over-representation and it was concluded that the peat resting on the High Buried Beach at Wester Kerse was a Sphagnum peat that probably accumulated in Salix scrub sometime during the latter part of Zone V of the pollen sequence.

Conclusion.

The results of laboratory analysis are somewhat restricted in the contribution that they make to the understanding of the buried raised beaches. Since the original samples were collected as the initial boring was being carried out, knowledge of the adjacent sub-surface conditions was often limited. Working through stratigraphical records, to build up an overall picture of the area under study, it became increasingly apparent that the samples were not always sufficient in number or collected from the points that would have provided the most information. However, this does not invalidate the results that were obtained. Indeed, in many cases, they can be cross-checked with geomorphological or stratigraphical factors, but their numbers and distribution place a restriction on the interpretations or conclusions that can be drawn. The laboratory analysis here is perhaps best seen as resembling a pilot study, inasmuch as the evidence obtained from it, together with the improved knowledge of the sub-carse features, should allow a more comprehensive study to be made of the mechanical and chemical properties of the buried features in the future.

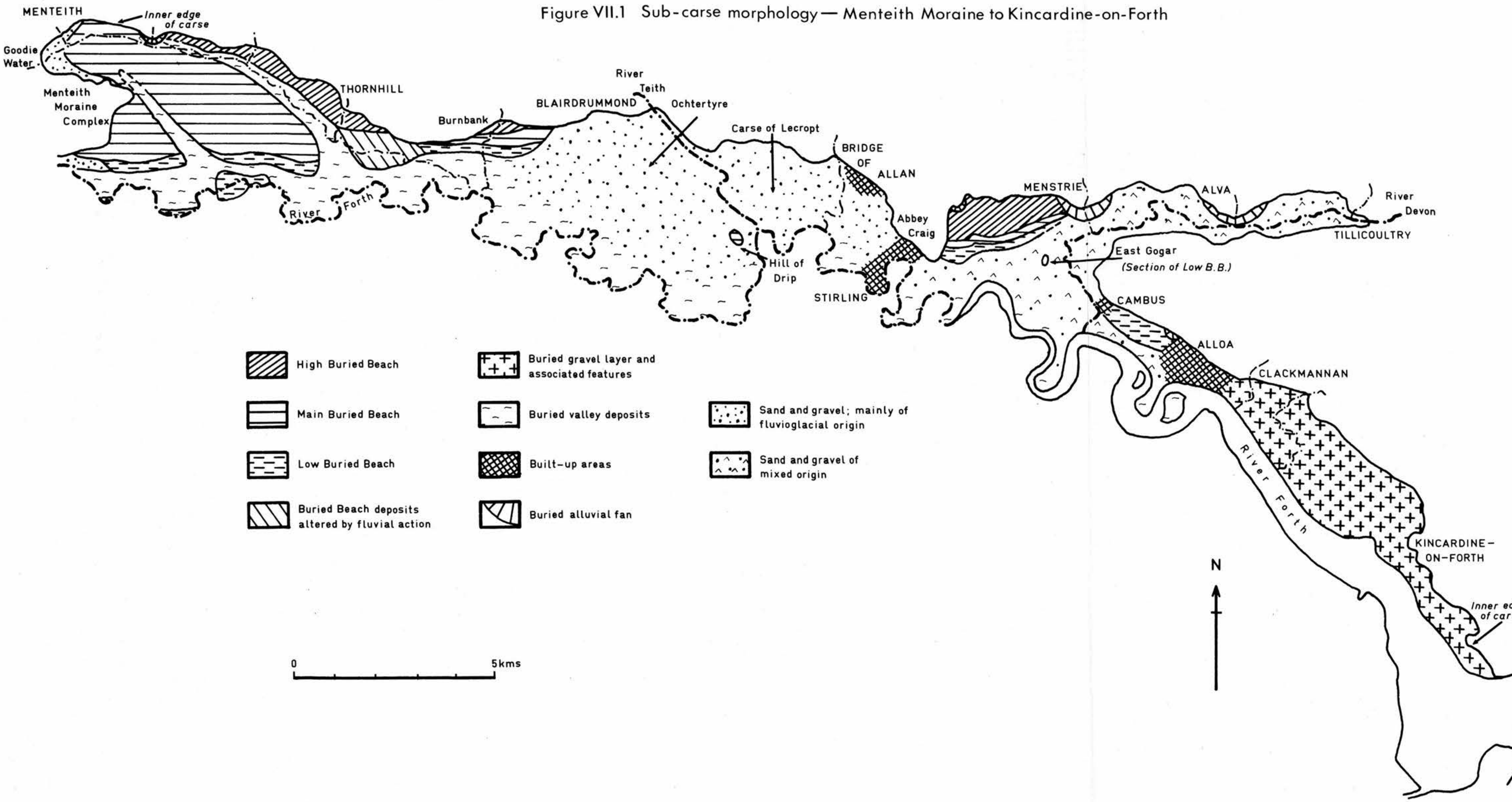
CHAPTER VII

A DISCUSSION OF THE STRATIGRAPHY AND SUB-CARSE MORPHOLOGY OF THE STUDY AREA AND THE SEQUENCE OF EVENTS THAT THEY INDICATE*

In the preceding chapters, it has been shown that the area between the Lake of Menteith and Kincardine-on-Forth can be divided into a number of smaller regions based on the sub-carse morphology. As in most cases where division is required, the boundaries are not absolute, but are based to a greater or lesser degree on convenience. For the three sub-areas already identified there are certain factors that make them decidedly different from each other, yet there are also factors common to all three. Some of these linkages from one area to another have already been indicated and the purpose of this chapter is to consider them more fully, at the same time examining the origins and relationships of individual features within the areas allowing a more comprehensive picture of the complete region to be built up. Furthermore, it has been pointed out above (Chapter I) that the present study is concerned mainly with the evidence of geomorphological activity during a period beginning with the maximum of the Zone III Readvance and terminating with the flooding of the Forth valley by the carse-sea. This being so, it is intended, in

*Figure VII.1 is applicable to this entire chapter.

Figure VII.1 Sub-carse morphology — Menteith Moraine to Kincardine-on-Forth



the first place, to consider the situation leading up to the point when ice stood at the Menteith Moraine, introducing other events, and the features associated with them, as far as possible in chronological order.

* * *

The Loch Lomond Readvance culminating about 10,300 years ago marked the last major Weichselian expansion of ice in Scotland. At its maximum, the ice moved from the Highlands into the head of the Forth valley, perhaps even extending its snout into a sea that stood at about 10.0 m O.D., and produced a conspicuous moraine (Chapter I). The moraine itself indicates a period of equilibrium during which the rate of ablation more or less balanced the rate at which new ice was being supplied, great quantities of outwash sands and gravels meanwhile being carried out into the sea.

One of the constituents of the moraine is a fossiliferous marine clay gouged out and redeposited by the advancing ice. From an examination of the included shells and comparison with similar deposits in the Loch Lomond area it has been concluded that the clay was laid down in an arctic climatic environment (Simpson, 1933), while radio-carbon assay has provided a date of 11,800 B.P. for the shells themselves (Sissons, 1967b). The term "arctic" as used by Simpson may be questioned as it is known that the Zone II period into which the sediments have been dated showed some climatic amelioration (West, 1968), compared with the preceding period, but it does not prevent the use of the term "Lateglacial marine clays" for these deposits.

Before, during and after the Perth Readvance, provisionally dated as reaching its maximal extent about 13,000-13,500 B.P., marine incursions deposited great thicknesses of silts and clays in the Forth valley. These have been examined in the Grangemouth area at various times since the second half of last century (Milne-Home, 1871; Cadell, 1880, 1913; Dinham and Haldane, 1932; Sissons, 1963, 1967a) and the general concensus of opinion, based largely upon the nature of included fossils is that the sediments were laid down in arctic waters.

Within the readvance limit, which, according to present evidence lay across the Forth valley in the vicinity of Kincardine (Smith, 1965), the arctic silts and clays were probably eroded or incorporated in newer deposits while outside the limits they were covered by sands provided by meltwater rivers. Most of these sands were redistributed by marine action to produce beaches later raised by isostatic adjustment (Chapter I). At the same time, away from the inner margins of the estuary the finer sediments were being deposited to continue the accumulation of Lateglacial marine sediments. At this point, then, the term "Lateglacial marine" has been applied to deposits formed prior to and during the Perth Readvance.

With the decay of the ice after the maximum of the readvance, the glacier margin retreated as far as the Stirling gap where a substantial halt or slight readvance took place. The retreating ice was replaced over the area between Stirling and Kincardine (including the Devon valley) by the advancing sea. The beaches associated with this sea now occur up to 38.0 m O.D. immediately east of Stirling, while clays or silts, reddish or reddish-brown in colour, are recognizable in numerous boreholes in the area. The clays and silts rest upon till in many places or may be separated from it by sand and gravel of probable fluvioglacial origin, while the fossils that they contain show them to have been deposited under arctic climatic conditions (Parthasarathy and Blyth, 1959).

While ice stood in the Stirling gap, the sea-level fell relative to the land as is indicated by the discrepancy in raised beach heights east and west of Stirling (Sissons and Smith, 1965a). West of the city no raised beach has been found above 23.0 m O.D. Despite the fall in level, however, the sea remained sufficiently high to cover a large area west of Stirling vacated by the decaying ice, leaving evidence of its presence in the fine clays and silts of borehole reports, and shells apparently associated with this incursion have been dated at 11,800 B.P. (Sissons, 1967b). Since the deposits from which they were obtained were not *in situ* it was not possible to link the date directly to a particular sea-level.

One of the main problems in this area is the paucity of deep commercial boreholes in which the Lateglacial silts and clays can be identified. Where they are present their surface varies in height from -10.2 m O.D. at Lecropt to +6.9 m O.D. at Blairdrummond. Farther west at Inch of Leckie and Bridge of Frew respectively, heights of -3.0 and -6.9 m O.D. have been measured, while at Westwood, between Blairdrummond and Lecropt, the surface of the clays and silts lies at +2.3 m O.D. In only one small area is there any obvious pattern to the altitude of the deposits and that is in the Carse of Lecropt where the borehole density is somewhat greater than elsewhere. Here, the Lateglacial deposits have been identified in a total of 19 boreholes. With one exception the surface of the deposits has been heighted at between +1.0 and -4.1 m O.D. and in twelve bores they lie within the narrower range +1.0 m O.D. to -2.0 m O.D. In addition to this, in the same area, where the clays and silts are missing from the stratigraphy, their place is taken by rock and till with surface heights falling within the same range. Furthermore, in one particular bore, the clays and silts are covered by a layer of brown sand and gravel 1.4 m thick while what is probably the same deposit can be identified in another borehole where it contains marine shells and rests upon a till surface at -0.2 m O.D. Unfortunately, shells are recorded only in one case but the concordance of levels from clay and silt to rock and till strongly suggests marine activity associated with a sea-level close to or slightly below Ordnance Datum.

Beneath the carse clay in the Grangemouth area, Sissons (1969) has identified a platform of marine erosion ranging in altitude from -6.0 m O.D. to +6.0 m O.D., but with the bulk of the erosion concentrated at or about present O.D., while a continuation of the feature to the north of the Forth has been described in Chapter V. There are several similarities between that feature and the one outlined in the Carse of Lecropt. In both areas the height ranges, within which the features lie, are closely comparable while the nature of each surface, truncating rock, till and silts and clays, is also similar. At the same time, marine shells have been found associated with both features.

As well as the similarities, there are differences, but most can be explained in terms of slight differences in local environment. A characteristic of the platform in the Grangemouth-Kincardine area is the widespread presence of a relatively thin gravel layer. Such a layer may be present at Lecropt, and it has possibly been located in one or two boreholes, but the stratigraphy is such that the silts and clays are often overlain by thick beds of sand and gravel that could make identification of the equivalent of Sissons' "buried gravel layer" very difficult. A slightly more sheltered environment at Lecropt might also explain the difference.

A more serious problem would seem to be the height relationship between the two areas. Taking isostatic factors into consideration, it might be expected that any equivalent of the Grangemouth-Kincardine feature in the west would have a greater altitude than the more easterly feature. Comparing altitudes at Lecropt and Grangemouth-Kincardine it can be seen that this is not so. However, several factors can be taken into account when examining this discrepancy. In the first place, since no shoreline has been located at Lecropt, it is not possible to decide the point on the Grangemouth-Kincardine feature from which heights should be taken for comparison. Again, in the Grangemouth-Kincardine area, while no shoreline gradient has been calculated, the general altitudes show little or no downvalley slope. This appears to be so at Lecropt also and as a result the height differential between the two areas would be expected to be low. Finally, at Grangemouth-Kincardine the Late-glacial sediments are overlain by a layer of gravel as much as 1.5 m thick, but commonly between 0.3 and 0.9 m, while at Lecropt the stratigraphy does not normally include such a layer. Depending upon the point at which the heights were measured, this in itself might have the effect of reducing the altitudinal differences. It would appear evident that the height relationship between the two areas is less serious than at first considered and, in fact, the general correspondence in height linked to the factors presented above does not preclude the two surfaces from being considered as separate parts of the same feature, namely a platform of marine erosion formed by a sea-level close to that of the present day.

This period of low sea-level has been provisionally dated by Sissons (1967a) as occurring sometime between 13,500 B.P. and 10,300 B.P. (Chapter I). It would seem possible, however, to reduce this time span somewhat. It is well established that the sea-level in the Forth valley was much higher than at present when the Perth Re-advance ice began to decay. Although the level did fall relatively rapidly while the ice front stood in the Stirling gap, it remained sufficiently high to produce the beaches now standing at about 20.0 m O.D. west of Stirling. Thus, the sea-level could not have been low enough to produce the buried gravel surface during the early part of the period. Timing the continued lowering of sea-level is a main problem in the Forth area (and during the period concerned) because of the limited number of radio-carbon dates available. In addition, results from other parts of the country can be applied only in a general way. Evidence from Northern Ireland, for example, suggests that the sea had fallen below its present level by 12,000 B.P. (Morrison and Stephens, 1965) and this agrees with the general trend established in the Forth. However, the distance of the areas from each other and their individual distances from the centre of isostatic uplift limits the usefulness of the comparison. Shells from sub-arctic clays incorporated in the Menteith Moraine have shown that marine sedimentation was still active there as late as 11,800 B.P. This being so, these clays must represent the latter stages of deposition from the sub-arctic seas, since close to the date obtained the Zone II amelioration of climate was beginning to take place. Due to the fact that the shells and surrounding sediments are not *in situ*, their altitude is not suitable for the estimation of sea-level, but Sissons (1967a) has inferred that the sea had fallen to about its present level, or slightly below, by the time the sub-arctic deposits of Scotland had ceased to accumulate. It is suggested, therefore, that the low sea-level in the Forth valley was reached slightly after 11,800 B.P. and by that time marine erosion was beginning to produce the surface characterised by the buried gravel layer.

As has been pointed out in the Grangemouth-Kincardine area the buried gravel surface and associated planated rock and till is encountered through the considerable range of -6.0 to +6.0 m O.D. and exists as a continuous feature within that range. It is considered that such a result would be produced by a gradually rising sea-level with the rate of rise balancing the rate of erosion and allowing the extension of the feature both altitudinally and areally. As the sea reached present datum, the rise may have slowed slightly, explaining the abundant records at about that height.

To return to the dating of the formation of the buried gravel layer and its related erosional surface, it is suggested that they were produced by the erosion of Lateglacial marine sediments, till and rock sometime between 11,800 B.P. and 10,800 B.P. With a time span of only 1,000 years, it might be argued that such a period would be insufficient to produce extensive erosion. However, certain local conditions that might accelerate erosion can be suggested. In the first place, it seems likely that some erosion accompanied the sea-level as it fell to its low circa 12,000-11,800 B.P. The steady rise in sea-level that followed could have made use of this in the formation of the final surface. Furthermore, in the area concerned, deposits such as Lateglacial marine sediments and till contain abundant rock fragments ranging in size from pebbles to cobbles and boulders, held together by finer materials such as clay and silt. The relatively easy erosion of the latter would make available sufficient of the larger constituents to allow reasonably rapid erosion of the adjacent rock, while the possibility of at least some glacial erosion of the rock surface, followed by modification by marine agencies, cannot be overlooked. Other factors such as increased storminess in the Forth may also have helped erosion, but it is thought that a combination of the circumstances mentioned would allow the buried gravel layer and its counterparts to be formed within the allotted time.

Considerable space has been used in an examination of these deposits normally termed "Lateglacial marine sediments", for two main reasons. Firstly, the term has been used somewhat loosely in the past. Part of the problem has been the limited information available and this remains a major difficulty. However, an attempt has been made above to show that deposits identified by that name are not necessarily of the same age. Secondly, in the Forth valley, this period of considerable geomorphological activity produced a base for the development of the later features with which the present study is more directly concerned and for this reason it was considered necessary to look at it, with its associated features, in some detail.

Buried outwash and associated gravel deposits.

Associated with the Menteith Moraine are a number of areas of outwash sloping eastwards down the Forth valley and indicating considerable meltwater activity as the ice of the Loch Lomond Re-advance decayed. On the north side of the Forth, the main mass of fluvioglacial gravel forms an outwash plain spreading out from a gap in the moraine now occupied by the Goodie Water, a small stream draining the Lake of Menteith. This outwash can be followed in an easterly direction for more than 3.0 km and over part of this distance it is buried beneath more recent deposits (Fig.III.2). Considering its relationship to the moraine, the formation of the outwash can be employed as a point of reference for the dating of these deposits. Previous work on this aspect has been described above in Chapter I and as the present study can add little to this, it will concern itself, at this stage, with sand and gravel deposits thought to have been formed contemporaneously with the Menteith outwash.

All along the northern edge of the carselands, between the Menteith Moraine and Blairdrummond, the streams passing out on to the carse show evidence of alluvial fan development. In most cases the fans can be seen to rest upon the carse, indicating relative ages, but boring has provided evidence that shows that fan formation began in Lateglacial times. At Rednock, Tarr and Ruskie, for example, not only do the fans pass beneath the carse, they also pass below the buried beach deposits. The Rednock Burn gravels are overlain by the grey silty sand of the Main Buried Beach, while the deposits of the High Beach rest on parts of the fans at both the other locations. Thus the lower parts of the fans are at least older than the High Buried Raised Beach. Furthermore, since the sediments of the latter ceased to be laid down in a very short time following the deposition of the outwash (Sissons, 1966), the fans cannot be younger than the outwash. They may have been initiated some time before this, but considering the environmental conditions associated with a decaying ice-sheet, it is probable that the fans were largely built up at the same time as fluvioglacial deposition was taking place downstream from the moraine, and, although the stratigraphical evidence is less positive elsewhere, it is suggested that the other fans at Rednock, Boquhapple, Norrieston, Craighead and Burnbank were growing at the same time.

Although considerably smaller, the features west of Blair-drummond are somewhat similar to the fans along the face of the Ochils, for which the stratigraphy and period of formation have been described in some detail in Chapter V. Unfortunately, no commercial boreholes pass through the former, but the overlying stratigraphy does show that they were well developed prior to the deposition of the buried beaches and continued to grow following this, as was the case with the Ochil fans. In the latter area, development appears to have been initiated while an arm of the sea extended into the Devon valley with the decay of the Perth Readvance ice, but in the west the initial growth must have come later as the ice retreated westwards. Nevertheless, whatever the time of origin, it is probable that both sets of fans were substantially augmented during the period of glacial decay that followed the Loch Lomond Readvance. While none of the fans was directly connected to a glacier outlet, and none was therefore supplied with glacial meltwater, it is considered that the melting of permanent or semi-permanent snow on the Menteith and Ochil Hills would add sufficiently to the supply of water to allow an increase in the transport of material abundantly available in unconsolidated periglacial and glacial deposits, to the fans.

Furthermore, from a climatic point of view, there appears to be no period between the end of the Zone III cold spell and the wetter Atlantic period during which there would have been sufficient water available for deposition of coarse material on such a scale (Manley, 1952). Since then, the fans have continued to grow from time to time, but, especially after the formation of the carse, the detritus has tended to be of a finer nature -- sand or coarse sand compared with the earlier gravel or sand and gravel -- and this is probably a reflection of a relative decrease in the vigour of the elements of erosion and deposition in more recent times.

The features considered above are small when compared with the alluvial fan of the River Teith. With its extension eastwards to Stirling, it covers a total area approaching 18.0 sq km while it is directly connected to gravel terraces in the Teith valley immediately adjacent to the present study area (Fig.VII.2). These terraces provide an insight into the origin of the fan, for it appears that they have been formed by the dissection of an outwash train that once filled the valley (Smith, 1965). Followed south-eastwards down the Teith, the terraces pass beneath the carse clays, but boring has shown that they form a continuous unit with the buried fan that spreads out from the point of exit of the river from the hills at

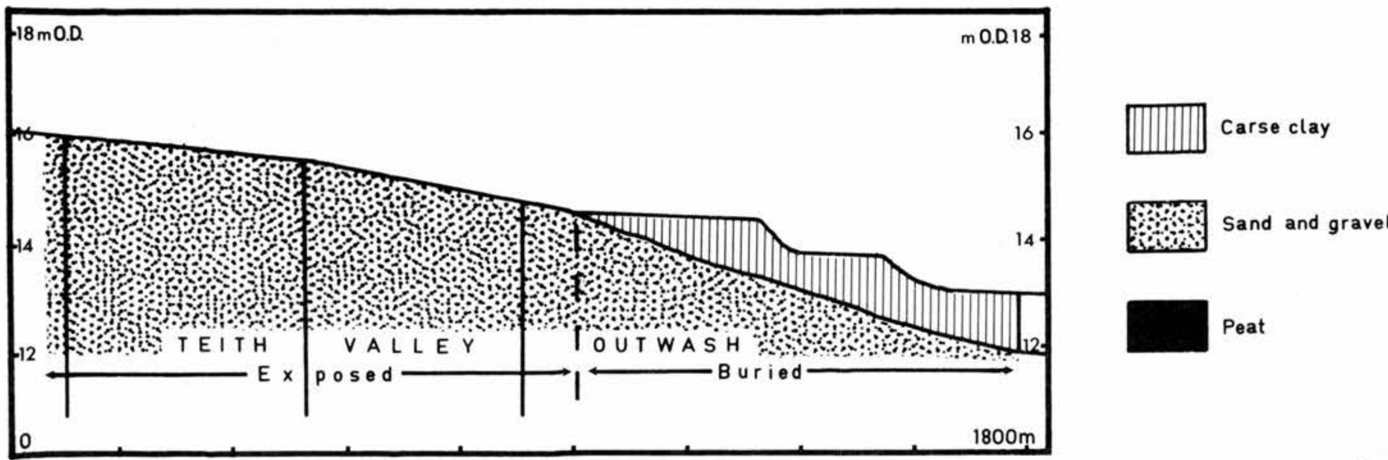


Figure VII.2 The sand and gravel deposits of the River Teith, near Blairdrummond (Various sources)

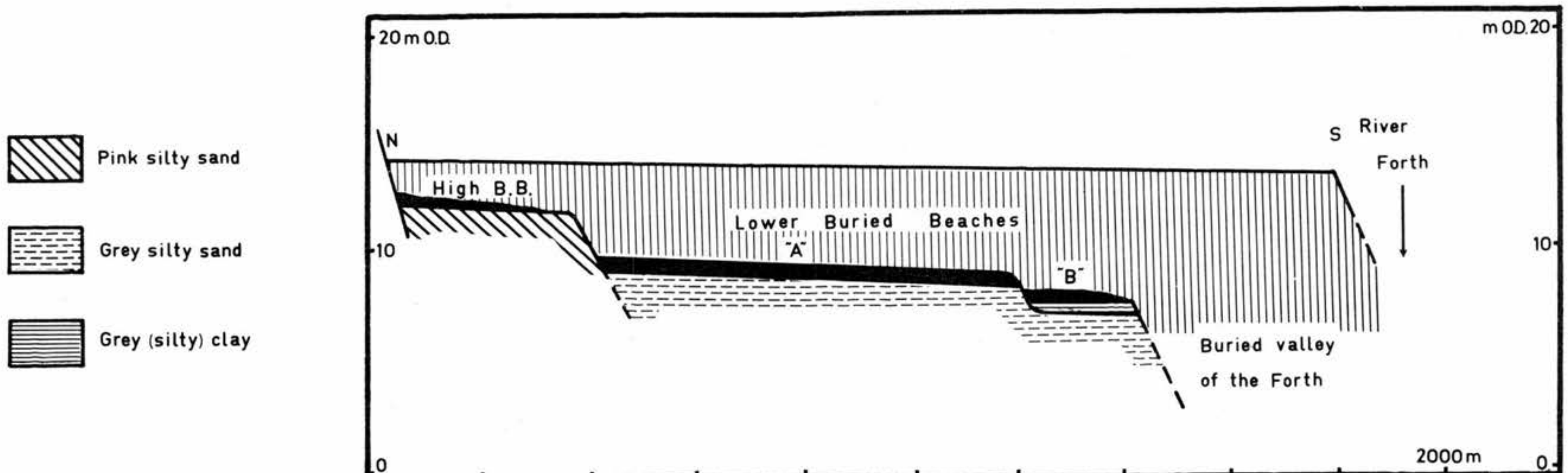


Figure VII.3 The buried beaches on the northern side of the River Forth

Blairdrummond (Chapter IV). The close link between fan and terraces suggests a common origin and it is considered that both were formed initially from fluvioglacial material carried down the Teith and out towards the Forth. Subsequently, the erosion that caused the formation of the terraces probably brought about an extension of the fan with the re-deposition of sands and gravel, while the changing course of the river undoubtedly altered its morphology.

Given the proposed fluvioglacial origin of the buried fan, the problem of dating its formation arises. The most recent glacial period with which fluvioglacial agencies can be associated is the Zone III Readvance. In the Teith valley, the exact limits of this event have not been located, but it is known that the ice extended to the vicinity of Callander (Sissons, 1965), and from that position meltwater could have carried the outwash downstream towards Blairdrummond. It is conceivable that during retreat after the Perth Readvance the Teith might have acted as routeway for meltwater carrying fluvioglacial material, but in the immediate area there is only one deep borehole and this does not allow any conclusions to be drawn.

Initially a roughly symmetrical fan might have been built up by a number of distributaries that frequently changed their courses as is common in such situations (Strahler, 1969). With time the bulk of the drainage became channelled into the main stream of the Teith and the deposits were spread out eastwards at least as far as the Hill of Drip and the Carse of Lecropt, but perhaps even reaching Stirling. Even today, the Teith carries gravel eastwards as can be seen in the bed of the river from Mill of Torr to Lecropt and at

Heathershot where a substantial mass of sand and gravel rests upon the carse and forms the core of a meander. Lenses of gravel within the carse, but away from the present line of the river are presumably indicative of a similar origin while the carse-clays were being deposited, indicating (together with the earlier and more recent evidence) the continuing ability of the Teith to transport coarser sediments from its valley on to and across adjacent lower areas. Assuming an abundance of meltwater during the decay of the Zone III ice and considering the borehole evidence of changes in position of the riverbed (Fig.IV.2), it seems entirely feasible to credit the waters of the Teith with the formation of the buried fan in the vicinity of Blairdrummond.

The above observation would appear to hold true for Lecropt also, where formlines on the surface of the buried gravel indicate a former course of the Teith through the area (Fig.IV.4). However, slight additions are required. In the western part of the Carse of Lecropt, close to the present River Teith, the buried gravel is commonly represented by a single band varying in thickness between 3.6 and 5.0 m and resting upon sediments interpreted above as Late-glacial in age. Contrasting with this in the east are a number of boreholes that show the gravel nowhere less than 10.0 m thick, with a maximum of 19.0 m, while the total thickness consists of a number of bands varying in texture from fine sand to large gravel, the whole overlying silts and clays similar to the Lateglacial sediments or occasionally till.

One explanation of the difference involves an examination of rockhead altitudes in the eastern and western parts of the Carse of

Lecropt. Although not all boreholes have reached rockhead, those that have, show lower altitudes in the east than in the west, by as much as 10.0 m and point to the possibility of a deeper basin to the east in which great masses of sand and gravel accumulated. The existence of such a feature could only be proved by additional deep boring, but, whether or not it is present, the extra material could have been supplied from local sources. Close to the eastern edge of the area, the Lecropt Burn and the Allan Water enter the carselands and it seems probable that the complexity of the gravel stratigraphy can be explained by the conditions produced at the confluence of these streams with the Teith.

In a few cases, where the gravel directly overlies till, a further possibility exists. The last ice to cover the area did so at the time of the Perth Readvance and it was presumably then that the till was deposited. With the retreat of the ice, and its halt in the Stirling area, fluvioglacial detritus was laid down in the form of a major terrace in the Bridge of Allan area (Dinham, 1927; Smith, 1965). Some material may well have been carried on to the ice itself to be deposited directly upon the till as the ice melted. With continuing deposition, especially following the Loch Lomond Readvance the present thickness of gravel was built up. Given the number and distribution of deep boreholes, this can remain only a possibility, although, considering the composite nature of the Ochil fans and the local site conditions, it would not seem out of place as part of the explanation for the accumulation of such a large volume of sands and gravels in this particular location.

In summary, it can be noted that while the ice of the Zone III

Readvance was decaying at Menteith and causing the development of an outwash plain in the upper Forth about 10,300 B.P., sand and gravel was being carried into the Forth basin at numerous points along its northern edge, to form or expand alluvial fans. Of these, the Ochil fans had already been in existence for a period of perhaps 2,500 to 3,000 years while fluvioglacial and fluvial gravels may have begun to accumulate slightly after this immediately west of Stirling. The period of initiation of the fans between Blairdrummond and Menteith cannot be deduced with any certainty, but it is considered that all were substantially augmented during Zone III, especially during the retreat of the ice and this appears particularly true in the case of the Teith fan. At a later date, the lower portions of most of the fans and virtually all of that of the Teith were buried beneath the deposits of the carse sea. Since then the fans have continued to grow, but less vigorously and this is reflected in the finer materials lying above the carse compared with those buried by it. Even today most of the fans are active, if only intermittently and in the case of the Ochil fans this represents continuing activity over a period of approximately 13,000 years.

The High Buried Raised Beach.

The above term was first used by Sissons (1966) in referring to a terrace or step lying close to, but slightly lower than, the carse shoreline in the western part of the Carse of Stirling, south of the River Forth. In this location it was covered by a layer of carse-clay 2.0-3.0 m thick, but separated from it by a thin band of peat. Since it is composed of fine-grained water-laid sediments that were adjudged to be of marine-estuarine origin and since it was both buried beneath the carse-clay, yet standing at a height above present Ordnance Datum, the term "buried raised beach" was applied to the feature. Further examination showed it to be only the highest of a suite of buried beaches, therefore the prefix "high" was added. In the area in which it was first identified, the beach was characterised by a major proportion of silty sand in its composition, the components being pink or pale-brown in colour except in the upper few centimetres where grey was more common. Finally, since altitude was being used in the differentiation of this beach from adjacent features, particular attention was paid to heights and levelling showed that close to its shoreline most of the surface stood within a range of 11.9 to 12.3 m O.D.

The present study has shown that there exists a comparable terrace extending for a distance of some 6.0 km downvalley from the Menteith Moraine along the northern edge of the carselands. In virtually every respect, the two beaches show a strong similarity that stretches through colour, composition and position with respect to adjacent features. Some differences are to be expected due to variations in local conditions, but any that do exist are relatively small. On the northern side of the Forth, for example, one borehole shows the High Buried Beach at a height of 12.9 m O.D. compared with a maximum of 12.3 m O.D. to the south. With reference to the buried peat layer that normally covers the surface of the southern beach to a depth of a few centimetres a further variation may be noted. To the north, the peat has been found to vary from almost nothing to as much as half a metre in thickness, but again this may be explained by small local differences in factors such as drainage. Overall, the differences are by far outweighed by the similarities and there appears to be no doubt that the two beaches represent the same period of marine-estuarine deposition.

Boreholes put down to the High Buried Raised Beach show that it exists without a break between Ruskie, close to the moraine, and Ballinton, almost 6.0 km to the east, with an altitudinal range of 12.8 to 10.3 m O.D. between these points. Absent for 2.0 km east of Ballinton, it appears again at Burnbank where it consists of a triangular area of coarse grey or pink sand and silty sand resting beneath an embayment in the carse shoreline with its apex at the point of entry of the Burnbank Burn on to the carse. Heights along the inner margin of this section range between 11.1 and 10.2 m O.D.

An examination of the sediments forming the feature bring to light two main points; firstly, a reduction in the coarseness of the deposits away from the inner margin and secondly, a change in colour and sometimes texture with depth. Close to the higher land, pink or red sandy gravel is often present immediately beneath the carse, in some cases mixed with grey sand (Boreholes 184, 185, 187, 670, and 697), and as the re-entrant of the Burnbank Burn is approached, the texture becomes noticeably coarser. As noted, similar changes are sometimes present with increasing depth in the deposits (Boreholes 691 and 696), but the most remarkable change is in colour. In this area, boreholes commonly reveal the following stratigraphy:-

4. Carse clay
3. Peat
2. Grey silty sand
1. Pink (silty) sand

The grey silty sand averages 20.0-30.0 cm in thickness and closely resembles the weathered layer normally associated with the surface of the High Beach (Chapters III and V).

From this evidence an attempt was made to deduce the origin of the feature. It was pointed out above that the Burnbank Burn is considered to have been one of the streams building fans out into the Forth valley at the time of the Zone III advance. This, plus the addition of material by mass-movement from the slopes rising behind the carse is regarded as having supplemented marine deposition at that time. It would also explain the increasingly coarse nature of the material towards the backslope and towards the stream. From the nature of the sediments, the form and the location of the feature, it is thought to represent the High Buried Raised Beach in this area.

Downvalley from Burnbank, the High Beach has not been encountered at all over a distance of 12.0 km. In a study such as this, the spacing of boreholes might prevent the identification of a feature, but, in this particular area, the location of individual boreholes or groups of boreholes is such that this appears rather unlikely and it is believed that either the High Buried Beach is non-existent in this area, or, if it does exist, the patches are extremely small (Chapter IV). Beyond Stirling, a feature that is in many respects similar to the High Buried Beach has been identified along the Ochil front from Abbey Craig at Stirling to Menstrie in the Devon valley (Chapter V). Thus, over the area concerned, two buried beaches that are possibly related to each other are present, but well separated by an area in which no comparable landform can be located. From these points, two questions arise. Firstly, is the feature east of Stirling a more easterly section of the High Buried Raised Beach? Secondly, why is the High Beach absent between Burnbank and Stirling?

For purposes of comparison, the two beaches can be examined in terms of a number of factors including form, colour, composition and stratigraphy. (Shoreline gradients can be compared also, but these will be considered separately along with the results from other beaches in Chapter VIII below.) Of these, similarities in surface form and colour are probably most obvious. Both sections are composed largely of pink or purple-pink sediments, the surface of which deviates little from the horizontal and has been only slightly dissected (Figs.III.4 and V.5). As the northern margin of each beach is approached the colour becomes more brown than pink and the surface becomes slightly hummocky perhaps due to the abundance of material supplied by solifluction or general downslope movement. The colour comparison can be carried further. It was pointed out (Chapter III) that in the High Buried Beach in the west, the topmost 5.0-10.0 cm were commonly greyish in colour rather than pink as if the sediments, originally pink, had been discoloured in some way. Such a discolouration is a normal feature of the buried beach along the Ochil front where it may affect the upper 10.0-20.0 cm of the deposit.

With reference to composition both similarities and differences exist. The general term "silty sand" has been used to cover the majority of sediments on both beaches, but, while it is almost everywhere applicable to the western section, there are significant differences in the east. Mechanical analysis has shown that on average the High Buried Beach in the west is the coarser of the two

(Chapter VI). However, in both areas, increasing coarseness of the beach material is apparent as the inner edge of the feature is approached and this is particularly so if alluvial fans are present. In the east, average values mask the coarseness of individual samples due to the modification produced by figures from an area in which pink clay, rather than pink silty sand, predominates. The clay has been found mainly in the angle between Abbey Craig and the Ochils and it is thought that the preponderance of fines -- as much as 73.5% of silt and clay in one sample -- is due to a location some distance from the source of the coarser materials, for the beach is over a kilometre wide at this point. This is the main textural difference between the two features, but it is thought that it can be explained in terms of local variations in sedimentation and does not preclude the possibility that they might be separate parts of the same beach.

In each case, the buried beach is only one element in the stratigraphy and the relationship with the deposits both above and below can be utilized to extend the comparison between the eastern and western features. In many places, the beaches proved too tough for penetration beyond the uppermost 10.0-20.0 cm with the Hiller borer and this imposed certain restrictions throughout the study. Nevertheless, where the deposits were thin or soft enough for penetration and where deeper commercial boreholes were available, the results showed a consistency that is common to both areas and has been summarised in Table VII.I.

TABLE VII.I

Sample boreholes from the Thornhill area and from south of the Ochil Hills, showing typical stratigraphy

THORNHILL	SOUTH OF OCHIL HILLS
Borehole 636 (NS 6368.0044)	Borehole 527 (NS 8162.9616)
4. Carse	4. Carse
3. Peat	3. Soft woody peat
2. Pink silty sand grading to pink sand	2. Brown-pink silty sand
1. Coarse sand and gravel	1. Coarse sand and gravel

It is suggested that the close correspondence between the stratigraphical columns, together with similarities in form, colour and composition allows the buried beach between Abbey Craig and Menstrie to be considered as an eastern counterpart of the High Buried Raised Beach of the Thornhill area.

A second problem that might be discussed at this point is the absence of the High Buried Beach in the area between Blairdrummond and Stirling. Taking heights on the beach section at Burnbank into account, it could be expected to stand between 9.0 and 10.0 m O.D. at Blairdrummond. Although the buried gravel in that area reaches heights of 11.0 m O.D. it slopes southwards and eastwards to well below 9.0 m. Thus, while the upper parts of the gravel would stand above the High Beach sea-level it might be expected that the beach sediments would form an apron over the lower areas. The borehole evidence shows that this is not so. As indicated the development of the High Buried Beach in the west took place after the deposition of the main mass of outwash and it is suggested that the outwash continued to be laid down at a later date in the Blairdrummond-Stirling area than farther west. At Menteith the local topography was such that as soon as the ice left the moraine the influence of meltwater on the depositional environment was severely restricted for its only exit eastwards was through the gap now occupied by the Forth. In contrast, coming mainly from the Teith, the meltwater farther east was being collected from a larger catchment area than at Menteith and had access to larger quantities of outwash. Fluvioglacial activity therefore persisted for a greater length of time than in the west disrupting the depositional conditions necessary for the formation of the beach. Any beach-form that did develop could have been destroyed or rendered unrecognisable by the changing positions of distributary streams on the fan. This possibility is strengthened by the fact that beaches formed after the High Beach do, in fact, encroach upon the fan in places, presumably owing their existence to a reduction in the vigour of fluvial activity.

In conclusion, it can be noted that the High Buried Beach exists as a recognisable entity in two areas on the northern side of the Forth valley, separated by a third area in which it may never have been present or may have been so altered as to retain no properties in common with the beach in adjacent areas. The High Buried Beach appears to have been formed from materials carried into the sea from the west and to a certain extent as a result of erosion of and mass-movement from Old Red Sandstone sediments and volcanics that formed the coastline at the time of its formation. In the present study it did not prove possible to obtain an independent date for the final formation of the feature, but stratigraphical considerations support the date of 10,300 B.P. postulated by Sissons (1966) for the corresponding beach on the south side of the Forth.

The Lower Buried Raised Beaches.

Of all the buried beaches, the High Beach with its pink coloration and position beneath the innermost edge of the carse is perhaps most distinctive. At lower levels, however, a number of other features have been located, easily distinguishable from the High Beach in terms of colour and composition as well as height but with similarities that can make them difficult to separate one from the other. These are the grey buried beaches composed of silty sand or clay lying to the south of the High Beach where it is present and at altitudes 1.0-4.0 m lower. They can be compared with the Main and Low Buried Raised Beaches of Sissons (1966) but in a number of respects the comparison requires some qualification.

The lower buried beaches have been found mainly in two areas, corresponding to those in which the High Beach was located, namely the area between Menteith and Blairdrummond and that between Stirling and the Devon valley. In addition, the lower beaches have been found to rest upon the Teith gravels, an area from which the High Beach appears to be completely absent. Within the two main areas mentioned, the lower beaches do not form the continuous features that the High Beach does and much of the difficulty in their interpretation is related to the fact that they form a number of isolated patches with only slight altitudinal and stratigraphical differences.

Although the various beaches have already been described in detail (Chapters III, IV and V), a short recapitulation will allow their locations and characteristics to be brought together for analytical purposes. In the area between the Menteith Moraine and Blairdrummond, the lower beaches are divided into two sections, just south of Thornhill, by the buried channel of the Goodie Water, which also separates the lower beaches from the High as far west as Ruskie where the latter appears to end. Eastwards from Thornhill, the High Buried Beach is encountered only in a small section at Burnbank and one of the lower beaches lies beneath the inner edge of the carse as far as the buried fan at Blairdrummond.

In the western section the lower beaches are two in number, differing mainly in terms of altitude and composition (Fig.III.4). Similarities in these two factors invite comparison with two buried beaches described by Sissons (1966) in the same general area, but to the south of the River Forth, and the higher beach on the north, composed of grey silty sand has been provisionally correlated with Sissons' Main Buried Beach, while the lower, composed of grey clay or grey silty clay, has been linked with the Low Buried Beach of the same sequence. In contrast to the normally distinctive features that characterise the Main and Low Beaches of the western section, there is considerable variety in altitude and composition in the stretch between Thornhill and the Blairdrummond fan. Although in terms of morphology there appears to be only one continuous feature (Fig.III.6) it varies in composition from relatively coarse grey silty sand to fine grey clay and in altitude from 10.8 to 8.5 m O.D. Mainly on the basis of composition and stratigraphy, this section was considered to contain parts of the Main and Low Buried Beaches.

Across the area underlain by the Teith gravels as far east as Stirling, the occurrence of the lower beaches is extremely limited.

In only two small areas at Sommer's Lane and Hill of Drip have buried beach sediments of any kind been located. They consist of grey or grey-green silty sand and from a general consideration of altitude, form and composition, it was concluded that they belonged to the Main Buried Raised Beach. With the analysis of the distribution of the lower buried beaches as a whole, this supposition may benefit from further examination.

Moving eastwards beyond Stirling, two lower beaches have been identified along the southern edge of the High Buried Raised Beach between Abbey Craig and Menstrie (Fig.V.5) with minor patches at East Gogar and Cambus. The latter is the most easterly location of any of the buried raised beaches on the north side of the Forth, excluding the buried gravel layer which, although marine in origin, differs morphologically and texturally from the other buried beaches. The features bordering the High Beach are relatively narrow, composed mainly of grey silty sand and stand at two different levels, the distinction being more obvious at Abbey Craig and less so nearer Menstrie. Although both are very similar in composition, the sediments of the upper beach overlap the southern edge of the High Buried Beach, which appears to have been eroded slightly, and this has a bearing on the stratigraphy. Pink silty sand is present beneath the sediments of the upper feature but not the lower. On the basis of this and a height difference of 1.0-2.0 m, a distinction was made between the two. From their position with relation to the High Buried Beach it was considered that the lower feature represented the Low Beach while the sediments resting upon the edge of the High Beach were part of the Main Buried Beach. Mainly on altitudinal and stratigraphical grounds, the smaller sections at East Gogar and Cambus, were assigned to the Low Buried Beach.

In establishing the relationships between the beaches of the region as a whole, comparison was made initially with the system established by Sissons (1966) for an area in the western part of the Carse of Stirling, mainly south of the River Forth. The situation in that area involved a relatively simple buried morphology with three beaches in a sequence in which the highest was oldest and the lowest was youngest. On the assumption that such a sequence would present itself in whole or in part, elsewhere in the Forth valley, it was taken as a reference. Within the three sub-divisions of the study area, each beach was assigned to one of the categories of High, Main or Low, in line with the sequence, which proved relatively easy where judgement was attempted within individual areas. Even with comparison between adjacent areas similarities were present, being strongest in the case of the two features considered equivalent to the High Buried Raised Beach. With the lower beaches, the similarities were less strong, necessitating slight changes in the basic system.

While the initial assumption, that the original sequence would be present, in whole or in part, in more than one area in the Forth valley, appears quite valid, several points arise. The boundary between comparison of features and the fitting of features into a preconceived sequence is a very narrow one and with this in mind the northern beaches were re-examined, in isolation, in an attempt to establish a pattern that could be compared as a whole with the sequence to the south of the Forth. This was applied only to the lower beaches, however, since it was considered that the similarity between the highest beaches both north and south of the Forth was sufficiently strong to leave little doubt as to their common origin. In itself, this was not thought to invalidate the technique since it can be taken to mean that the upper element of any pattern recognised north of the Forth is already comparable to the upper element of the sequence south of the river. The factors taken into account when comparing the High Beach sections at Thornhill and east of Stirling were again employed in considering the lower beaches.

The most extensive of these beaches was located in the western part of the study area, stretching for 10.0 km down valley from a point near the moraine and with a width of as much as 2.0 km. In composition it proved remarkably homogeneous, consisting of grey silty sand with occasional patches of grey clay on its surface. Along the southern edge of that major area of buried beach sediments and up to 2.0 m lower than it, a smaller beach was identified (Chapter III). It is present as an almost continuous feature along the southern edge of the higher beach, the only break being caused by the buried channel of High Moss Pow. Despite the difference in size, the two features have certain basic similarities. Both are grey in colour, forming relatively level steps beneath the carse clay, the latter normally separated from them by a layer of peat. Beyond colour, form and general stratigraphy, similarities are less, but still present to a certain degree. For example, grey silty sand makes up part of the substance of both features, although the lower of the two has a surface consisting of as much as 30.0 cm of sticky, grey silt or clay, before the silty sand is encountered. With factors such as altitude and gradient (Chapter VIII), the differences become greater, leaving no doubt that there are two separate features present.

For explanatory purposes, from this point on the upper beach will be referred to as buried beach "A" and the lower as buried beach "B".

The situation existing in the west appears to be paralleled in the section between the confluence of the Goodie Water with the Forth and Blairdrummond. At two points, namely Coldoch and Woodlane, the boreholes show the presence of two buried beaches, differing slightly in altitude. Furthermore, the upper feature is composed of grey silty sand for the most part while the lower also consists of these sediments, but only beneath a surface layer of sticky, grey silt or clay. Although the altitudinal differences between the beaches were found to be slightly less at Coldoch and Woodlane than farther west -- 0.8 m compared with 2.0 m -- the textural differences are equally strong and the layer of clay on the lower beach surface is often more distinctly separated from the underlying silty sand than in the west. Completing the stratigraphy, the buried peat layer normally covering both beach surfaces in the west is also present at Coldoch and Woodlane.

In the basis of colour, composition, stratigraphy and form, the evidence for the correlation of the two pairs of beaches was thought to be strong. When altitudes were compared similarities were also apparent. In the case of beach "A", for example, west of the junction of the Goodie Water and the Forth, the lowest altitude is reached close to its eastern limit with a value of 9.0 m O.D., which compares well with 9.2 m O.D. at Coldoch, 9.4 m O.D. at Woodlane and a number of others close to the 9.0 m mark, all on grey silty sand.

Based on these factors, the grey silty sand and grey silty clay beaches between Coldoch and Woodlane are correlated respectively with beaches A and B described in the west between Menteith and Thornhill. In turn the upper, grey silty sand and the lower grey silty clay beaches between Coldoch and Woodlane will be referred to as beaches "A" and "B".

Before attempting to relate the buried beaches existing between Menteith and Blairdrummond to those east of Stirling, some discussion is required concerning the isolated patches of beach material at Sommer's Lane and Hill of Drip and the general absence of such deposits over a much larger area between Blairdrummond and Stirling. At Sommer's Lane it was not possible to locate the shoreline and as a result the heights obtained cannot be directly related to those on the major sections of beaches "A" and "B". Averaging 8.0 m O.D., however, they are close to the altitudes expected for beach "B", but the deposits do not coincide, being grey silty sand rather than grey silty clay. From its location and the adjacent stratigraphy (Chapter IV), it is considered that this buried beach section has been altered after its formation, perhaps by fluvial processes associated with the Teith gravels, and because of this, as well as its extremely limited extent it was not examined further.

At Hill of Drip, sedimentation must have been complicated by the presence of rock outcrops, channels within the rock and sands and gravel brought down by the Teith (Fig.IV.5), but the buried beach deposits that exist are quite distinct and it is apparent that the

Hill stood out as an island at the time of their deposition. The sediments are often present in two distinct layers, the upper being grey (silty) clay and the lower, grey silty sand (Boreholes, 307, 308, 312, 346 and 354), inviting comparison with beach "B" in the west. In a number of places the clay is absent and the sediments appear comparable to those of beach "A". However, it is not possible to relate the difference in texture to difference in altitude and on the basis of present evidence it is considered that the two sediment types are part of one feature. Although it has characteristics that allow it to be linked with either of the western beaches, heights of between 8.1 and 8.6 m on the Hill of Drip shoreline are at least a metre higher than those estimated from the gradient of beach "B" between Menteith and Thornhill. Mainly for this reason, it is suggested that the buried beach deposits at Hill of Drip are probably best correlated with the higher feature -- beach "A" -- in the west.

On the question of the absence of buried beach deposits over large areas between Blairdrummond and Stirling, much of the discussion of the High Buried Beach is again considered applicable here. The presence of the River Teith with its tributaries and distributaries, flowing over the outwash fan was probably sufficient to prevent the quiet conditions of sedimentation implied by the fine texture and remarkably homogeneous nature of the buried beach deposits. In this situation, the streams flowing across the relatively unconsolidated outwash must have changed course frequently leaving very little of the area outside their influence. Even where deposition of the beach sediments did take place the changing position of a stream could easily have altered the depositional environment or initiated erosion to retard the growth of the feature or destroy it. Thus, it is suggested that the absence of buried beaches between Blairdrummond and Stirling was due to unfavourable conditions of sedimentation in the first place coupled with subsequent erosion by the streams of the Teith system in the areas where deposition was possible.

East of Stirling, between Abbey Craig and Menstrie, a suite of two lower buried beaches exists along the southern margin of the High Buried Beach. At first sight these appear to be similar to the two lower beaches between Menteith and Thornhill, like them consisting of grey silty sand with grey silty clay and occupying a similar position with respect to the High Beach. However, closer investigation shows some distinct differences.

The upper, grey silty sand beach east of Stirling stands at heights between 6.6 and 7.5 m O.D., some 0.3-1.0 m lower than the High Buried Beach in the same area and appears to occupy a bench approximately 200.0 m wide cut into the southern margins of that feature (Figs.V.4 and V.5). The stratigraphy of the bench area can be represented as follows:

4. Carse clay
3. Peat
2. Grey (green) silty sand
1. Pink silty sand

Such a situation is also found in areas where the High Beach proper is present, for the top few centimetres of the deposits of that beach are commonly grey in colour, but there are certain significant differences. In the first place, the grey sediments on the High Beach are usually very thin with a maximum thickness of 20.0 cm compared with 30.0-45.0 cm for the lower feature along its southern edge. Secondly, the boundary between the grey and pink sediments on the High Beach is diffuse while in the stratigraphy outlined above the change is normally very sharp. Finally, as can be seen in Figures V.4 and V.5, there are distinct altitudinal differences between the two features. They are therefore recognised as separate entities in the sub-carse morphology of the area.

While the differences allow these features to be considered separately, they are not completely unrelated. The evidence suggests that at some time in the past the High Buried Beach occupied the whole area now shared with the adjacent grey silty sand beach. Subsequent changes in sea-level caused its outer edge to be eroded into the form of a step or bench upon which the grey silty sand was deposited. This supposition is supported by the form of the bench itself. Its inner edge is quite strongly marked suggesting erosion rather than continued deposition at a lower level and perhaps indicating erosion by a rising sea-level. At the same time, the sharp boundary between the pink and grey silty sand on the bench appears to accord with this suggestion.

One additional point requiring examination is the change from erosion of the pink silty sand to the deposition of the grey sediments. Such a situation is not uncommon in coastal geomorphology where sand or shingle can be found resting upon an abraded platform (Sparks, 1965). In that case the deposits are normally provided by the erosion of the platform and its associated cliff or by longshore drift from an adjacent area and bear some geological or textural relationship to them. In the area presently under consideration, while there is a textural similarity between the deposits, they differ in colour and source. The part played by the Old Red Sandstone rocks of the area in the development of the pink silty sand has already been noted and it has been suggested that the grey deposits have a more distant source in the Highland rocks to the west and north of the Forth valley (Chapter III). Taking all this into account, the following is advanced to explain the formation of the feature. After the development of the High Buried Raised Beach, sea-level fell somewhat, only to return later, gradually rising and eroding the outer edge of the beach until it reached an altitude of 0.3-1.0 m less than the beach surface, where conditions seem to have stabilized, causing the rate of erosion to slow down. At about the same time grey silty sand was being carried into the sea from the west (and probably with some contribution from the Devon valley), in ever increasing quantity and deposition took over from erosion as the main activity along the littoral.

The deposition of grey silty sand on the step cut in the High Beach appears to have been only the beginning of a relatively lengthy period of sedimentation in the area, for an additional terrace of the same material is present along the southern edge of that feature. With altitudes of 5.7-6.8 m O.D. it lies between 0.9 and 1.3 m lower than the adjacent composite beach, and is entirely composed of grey sediments, no pink being present even at depth. It is thought to represent an area of deposition outside the former limits of the High Buried Beach, but contiguous with it, in which sedimentation took place after a slight fall in sea-level following the laying down of the grey silty sand on the High Beach step. At its widest it exceeds

400.0 m, narrowing towards the east and ending abruptly on the south above what is presumably the buried valley of the Forth.

In composition, the beach is almost entirely grey silty sand with only occasional patches of clay on its surface and is therefore texturally very similar to the grey deposits on the next highest beach in the area. In addition, comparison can be made with the features to the west where buried beach "A" and the deeper parts of beach "B" are of similar composition. Following on from this initial development it became obvious that the comparison could be extended to cover groups of beaches. Immediately east of Abbey Craig, for example, the buried beach sequence can be outlined as follows, working from highest to lowest:

1. The High Buried Beach consisting of pink silty sand.
2. A beach composed of grey silty sand resting upon the eroded edge of the High Beach.
3. A beach composed almost entirely of grey silty sand, with surface patches of clay.

This can be compared with the group identified at Burnbank, again working from highest to lowest:

1. The High Buried Beach of pink silty sand.
2. Beach "A" consisting of grey silty sand, the upper member of a suite of two lower beaches beneath the western part of the carse.
3. Beach "B", the lower member, composed of grey silty clay resting upon grey silty sand.

Looking at these lists it is apparent that certain similarities exist, both with individual features and with the features as a group.

As described above beach number 2 at Abbey Craig has a number of characteristics such as colour, composition, form and position in the stratigraphy, in common with beach "A" at Burnbank and it is suggested that these two features can be correlated with each other. The absence of a High Beach step at Burnbank may present an initial problem. Occasionally the grey silty sand of beach "A" at Burnbank is found to have some pink coloration with depth (Boreholes 689, 693, 695 and 707), but there appears to be nothing to compare with the composite feature at Abbey Craig. This, however, does not prevent their correlation. The two areas are almost 12.0 km apart and, considering isostatic factors, it is probable that the altitudinal relationship between the High Beach and that immediately below it differs from one area to the other.

Similarly, beach number 3 at Abbey Craig may be equated with beach "B", although again slight differences do exist. The layer of grey silty clay that is characteristic of the beach surface in the west is quite patchy at Abbey Craig, grey silty sand being the predominant sediment type. This coarser deposit may be due to the provision of sandier material by the Devon and the complicity of the river is suggested at East Gogar where an isolated section of buried beach has been identified (Fig.V.8). It stands at heights between 5.8 and 6.4 m O.D. with a surface consisting of 30.0-40.0 cm of grey silty clay resting upon grey silty sand and it is regarded as part of beach number 3. As on that beach, the grey silty clay cover is not continuous and it is considered that this was brought about by the changing position of the Devon and possibly the Forth. This is supported by the presence of fluvial gravels around and beneath it as well as by former river courses cut in the carse, showing that the rivers have been capable of changing their courses in the past.

At Cambus the buried beach sediments occupy a slightly more extensive area. As described in Chapter V they consist of grey silty clay resting upon grey silty sand beneath which lies a gravel surface (Fig.V.6). The stratigraphy is well marked and with the shoreline heights between 5.3 and 5.9 m O.D., the feature is considered to represent beach number 3 in this area. Along with the sections at East Gogar and between Abbey Craig and Menstrie, the beach at Cambus has been correlated with buried beach "B" at Burnbank.

Thus, beneath the carselands east of Stirling, three buried beaches have been recognised and have been correlated with similar features at Burnbank.

This can be taken farther, however, for the sequence at Burnbank has already been related to that between Menteith and Thornhill and the High Buried Beach, east of Stirling has already been shown to correspond to that at Thornhill. It is therefore possible to consider the buried beaches in the complete study area and this can be approached by means of a relatively simple model constructed by the combination of the beaches (excluding that represented by the buried gravel layer) known to exist beneath the carse on the north side of the Forth between the Menteith Moraine and Kincardine-on-Forth.

As represented in Figure VII.3 the model can be seen to consist of three distinct and contiguous levels, the highest lying beneath the inner margins of the carse and the two others becoming successively lower towards the Forth. The highest step, designated

"High Buried Raised Beach", is characteristically composed of pink silty sand and descends at its southern edge to "Lower Buried Raised Beach A". The grey silty sand of the latter is also one of the components of the next beach in the series, namely "Lower Buried Raised Beach B". This lowest level lies to the south of beach "A" and is composed of grey silty clay overlying a grey silty sand substratum, that possibly represents the eroded edge of buried beach "A", but there is no evidence to support such a supposition. Buried beach "B" ends abruptly before the Forth is reached.

Within the study area this sequence is not always present in its entirety or exactly in the form outlined above. At Thornhill, for example, the High Beach and beach "A" are separated by the buried valley of the Goodie Water and there is no step along the outer edge of the High Beach similar to that on which beach "A" rests in the east. Again, in the stretch between Coldoch and Burnbank, the High Beach is lacking, only the lower beaches "A" and "B" being present while the almost complete absence of buried beaches above the Teith gravels and between Cambus and Kincardine-on-Forth has already been remarked upon. These discrepancies have been described in Chapters III, IV and V and while any one may seem a significant omission in one particular area, they are not inexplicable and there is sufficient overlap between areas to allow the postulated model to be regarded as indicative of the buried beach sequence in the area as a whole.

At the beginning of this section reference was made to the buried beach sequence established by Sissons (1966) in the western part of the Carse of Stirling and south of the River Forth. It now appears pertinent to re-examine that sequence and compare it with that proposed above. It has already been shown in an earlier section that Sissons' High Buried Raised Beach was the equivalent of the highest beach to the north of the Forth. In addition, the Main and Low Buried Beaches described by Sissons (1966, 1967a) and referred to in Chapter I bear a strong resemblance to those now named Lower Buried Raised Beaches "A" and "B" respectively and originally described in Chapter III at which point the similarity was first noted. It is considered that on the basis of similarities in colour, texture, form and stratigraphy described in these chapters the two sets of beaches can be regarded as the equivalent of each other and summarised as follows:-

Buried beaches according to Sissons (1966)	Buried beaches of the present survey
1. High Buried Raised Beach	1. High Buried Raised Beach
2. Main Buried Raised Beach	2. Lower Buried Raised Beach "A"
3. Low Buried Raised Beach	3. Lower Buried Raised Beach "B"

Because of the obvious relationship between the two groups as well as for convenience and continuity it is proposed to retain the original names for the lower beaches, beach "A" becoming the Main Buried Raised Beach and beach "B" becoming the Low Buried Raised Beach.

While the position of the lower beaches with respect to each other and to the higher beaches gives some indication of their relative ages it was not possible to assign absolute dates to the features. On the south side of the Forth, however, two dates have been obtained. The age of the Main Beach has been inferred from the pollen analysis of peat resting upon its surface (Newey, 1966). The base of this peat was found to correspond to the transition between Zones IV and V of the pollen sequence equivalent to an age of about

9,500 years. In the case of the Low Beach, an age of 8,800 years was estimated from a consideration of pollen analysis and radio-carbon assay. At both sites the peat immediately above the beach contained *Chenopod* pollen indicating marine conditions and implying that the peat began to grow as the sea that formed the beach retreated (Chapter I). Thus the dates obtained could be considered to give a reasonable representation of the time of formation of the beaches.

Although these dates refer to features on the south side of the Forth completely separated from those to the north and although they pertain only to the western part of the area it seems unlikely that they would differ to any great extent from those in the east or north of the river. A check has been provided by the pollen analysis of the peat resting on the Main Buried Beach beneath East Flanders Moss (Durno, 1956). The lowest metre of the peat was found to belong to Zone V of the pollen sequence dated by Godwin (1961) at about 9,550-9,000 B.P. and on the basis of the thickness of the peat Sissons and Smith (1965b) were of the opinion that the beach had been formed by the earlier part of the period dating it at 9,500 B.P. The only other date for peat overlying buried beach sediments north of the Forth is one at Littleward near Thornhill giving an age of 3,250 years (Chapter I). The beach concerned is the Low one, but either the date is in error, or the peat measured is not part of the "buried peat" as described in the present study, for it is known that by 3,250 B.P. the carse clay that overlies the Low Beach and its associated peat had already been deposited.

The Buried Valleys.

From the evidence of both shallow and commercial boreholes it is apparent that the rivers and streams of the study area formerly flowed in valleys now buried beneath the carse. These buried valleys are most obvious in the case of the larger rivers such as the Forth, the Teith and the Devon, but even medium sized streams such as the Goodie Water (Fig.III.5) and comparatively small streams such as High Moss Pow show evidence of former channels beneath the carse. In places the valley beneath the Forth exceeds a kilometre in width while even the Goodie Water channel reaches 400.0 m. The Forth channel is the principal one, stretching for the whole length of the study area, while the others are tributary to it.

All the buried valleys are characterised by, and most can be identified by, the absence of buried beach sediments, explicable either in terms of non-deposition or deposition and subsequent erosion. Of these two possibilities, the former appears more likely, for several reasons. The larger valleys such as the Forth and the Devon are only part of much deeper features, consisting of a number of glacially eroded rock basins with rockhead standing at as much as 205.0 m below sea-level. (Chapter I).

An examination of the Teith shows that its buried valley is entrenched in the sands and gravels of the Blairdrummond fan (Figs. IV.2 and IV.4). Any earlier valley must have been filled in by these outwash deposits during deglaciation following the Loch Lomond Readvance and the river eventually carved a new course through the sands and gravels. In the west, the buried valleys of the Goodie Water and High Moss Pow may have developed along similar lines with respect to the Menteith outwash. Both seem to pass out from the gap in the Menteith Moraine now occupied by the Goodie Water and it is suggested that at different times during the decay of the Menteith lobe both carried meltwater eastwards, probably aiding in the distribution of outwash in the first place but later establishing their courses by erosion. In this the Goodie Water may have been aided by water carried in by the Rednock, Tarr, and Ruskie Burns.

The stream courses in the west probably continued to develop even after the flooding in of the sea to form the buried beaches. Considering the position of the beaches at the head of a long estuary, it seems reasonable to suggest that for at least part of each day they stood above the water as mud-flats, at which time the valleys would contain streams similar to those that cross the mud-flats in the Kincardine area at present, allowing any sediments that had been deposited to be removed. No doubt the flushing action of the tides would also help in this respect. At this time the High Moss Pow was probably carrying the drainage from the Lake of Menteith, while the Goodie Water received water from the burns of the Menteith Hills. Several factors prompt this suggestion. Firstly, it is unlikely that two streams would pass through the same gap in the moraine and flow in different directions. Secondly, the upper part of the Goodie buried valley, beyond its junction with the Ruskie Burn, is filled with the sediments of the Main Beach. Thirdly, if the drainage of the Lake of Menteith had flowed out via the Goodie Water, it would have deprived the High Moss Pow and allowed it to be filled, to some extent at least, with buried beach sediments.

As the sea-levels rose and fell during the formation of the buried beaches, the smaller channels probably changed from tidal creeks to river valleys and back again, while the larger features such as that of the Forth remained estuarine, the main change being in extent. The latest date at which the sea was confined to the buried valley of the Forth has been estimated by Sissons (1966). From the age of the Low Buried Beach it was known that the sea-level had fallen below it by 8,800 B.P. and by dating the peat on the beach surface where it merged with the overlying carse-clay it was possible to calculate the date by which the sea had risen again to flood over the peat. The date obtained was 8,270±160 B.P. and, allowing time for the rise to take place, it was estimated that minimal sea-level was reached in the buried valley close to 8,500 years ago.

From that time the sea-level began to rise, gradually submerging the buried beaches. The approach of the sea can be identified in the buried peat layers by an increase in *Gramineae* and *Chenopodiaceae* pollen as the junction with the carse-clay is approached. At two places in the west the rate of growth of the peat linked with continued isostatic uplift enabled it to maintain itself above the rising carse sea producing two areas of non-deposition of carse-clay (Sissons and Smith, 1965b). In most places, however, the submergence was complete, reaching a maximum by 5,500 B.P., causing the burying of the beaches and the infilling of the valleys by carse-clay. The persistence of the valleys during the formation of the buried beaches and their later filling with the deposition of the carse-clay may be explained by the different amounts of submergence involved. The carse sea stood considerably higher than those that formed the buried beaches. As a result, the valleys must have been for the most part below low tide mark at the maximum of the carse sea and therefore did not undergo the flushing action they had experienced previously. In addition all of the buried beaches were formed within a 1,500 year period and sea-level fluctuated considerably during that time. On the other hand submergence by the carse sea was much more uniform and lasted for approximately twice as long allowing greater and more extensive sedimentation. Even after this, however, there was probably some surface manifestation of the buried valleys for the present stream courses often follow the general lines of these former valleys.

Summary of Events.

1. Following the Perth Readvance of some 13,000 years ago sea-level fell by stages reaching a low slightly below the present level by 11,800 B.P.
2. A rise from this low level accompanied by erosion of Lateglacial marine sediments, till and rock produced the buried gravel layer.
3. The continuing rise reached 10.0 m O.D. sometime during the halt of the Loch Lomond Readvance ice at the Menteith Moraine.
4. With the decay of the ice outwash was carried into the head of the Forth valley. At the same time sand and gravel was being laid down in the form of fans all along the northern edge of the Forth basin, particularly at Blairdrummond and along the face of the Ochil Hills.
5. Within a very short period close to 10,300 B.P., after the main deposition of the outwash but before the complete decay of the ice the High Buried Raised Beach was formed.
6. After a short period of low sea-level, a rise allowed the

development of the Main Buried Raised Beach dated at 9,500 B.P.

7. An additional fluctuation of a fall in sea-level followed by a rise produced the Low Buried Raised Beach along the southern margin of the Main Beach. This was completed by 8,800 B.P.
8. A final lowering caused the sea to be confined to a relatively narrow estuary by 8,500 B.P.
9. The subsequent submergence beginning shortly after that and reaching a maximum by 5,500 B.P. caused the earlier beaches to be buried beneath the layer of carse-clay that forms the present surface.

CHAPTER VIII

THE ALTITUDES AND GRADIENTS OF THE BURIED BEACHES

Much of the early work on Scottish raised beaches stressed altitudinal relationships, particularly with reference to the supposed 25, 50 and 100 foot levels, and correlations were made over considerable distances based on altitude alone, on the premise that the features were horizontal. More recently, however, investigators have examined the relationship between the beaches and the isostatic recovery that followed the last glaciation, emphasising the sloping, rather than horizontal shorelines produced by differential uplift (Chapter I). The amount of uplift involved has been shown to depend on two factors; the position of the beach with respect to the area of maximum isostatic compensation and the period of formation of the feature.

Until quite recently, the sloping nature of shorelines in estuarine locations, such as the Forth, was linked to the increasing effects of tidal range towards the head of the estuary. While this undoubtedly does play a part in causing shoreline tilting it is normally considered to be extremely limited when compared with isostatic rebound. Using evidence from the present shoreline in the Forth, Smith (1968) has shown that the greater part of the differential elevation of the carselands is due to isostatic effects and since the present study is concerned with the same general area, his findings have been applied to the shorelines of the buried beaches.

In Scotland, the centre of isostatic recovery is considered to lie in the south-western Grampian Highlands (Donner, 1959) and outwards from that area the amount of uplift diminishes, the maximum decline taking place along a line drawn at right angles to the isobases. Figure VIII.1 shows isobases drawn for the Main Postglacial Raised Beach, for which the greatest quantity of altitudinal information is available, and it can be seen that the line of the Forth valley cuts the isobases at a high angle. While these isobases apply to only one period of time, it is considered unlikely that the basic pattern would differ markedly for other periods and it would be expected that other beaches would be similarly affected by increased uplift towards the west causing the surface to slope up in that direction. Such slopes have been demonstrated for a number of raised beaches in the Forth valley (Chapter I) and it would appear to be in order to infer a similar condition for the buried beaches.

As pointed out above, a second factor influencing the slope of raised beaches is the age of the features. This is based on the fact that older beaches have been experiencing uplift for a longer period of time than their more recent counterparts while it has also been shown that uplift has not always been constant. The greatest rate of uplift appears to have been achieved relatively soon after the decay of the ice and has since slowed considerably (Flint, 1957; Sissons, 1967a). For the Gulf of Bothnia, for example, Gutenberg (1941) has estimated that the present rate of uplift is only about two-thirds the average maintained during the last 7,000 years while for the Stirling area in the Forth valley, Sissons (1962) has

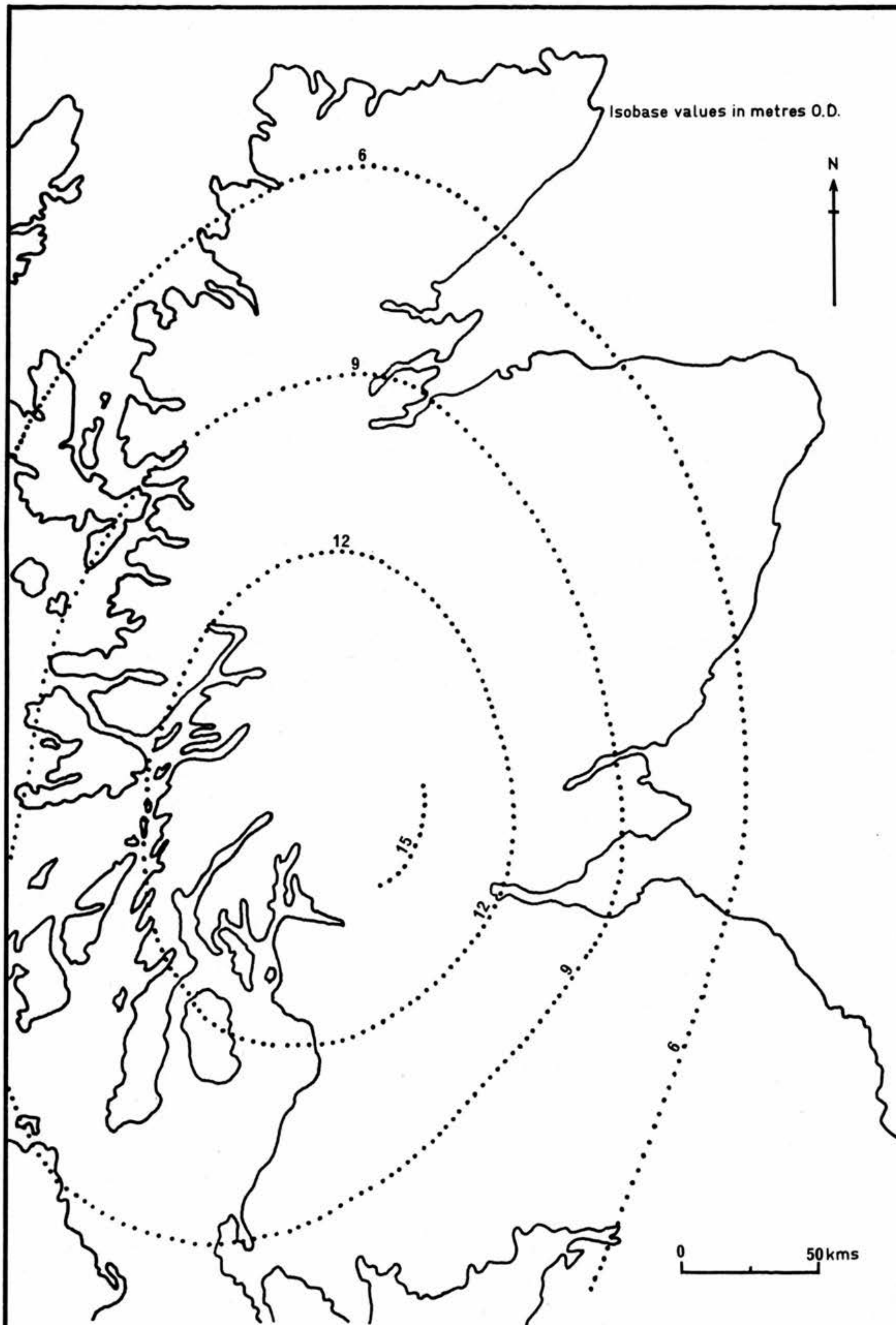


Figure VIII.1 Isobases for the Main Postglacial Shoreline

(After Sissons, 1967a.)

estimated that in the 5,000 years prior to the formation of the Main Postglacial Raised Beach uplift was taking place at a rate of almost 0.9 m per century compared with a rate of slightly less than 0.15 m per century since then. The net result is that the older beaches should have considerably steeper gradients than those formed more recently and this pattern appears to be present in the Forth. The oldest Lateglacial shorelines identified in East Fife have slopes of as much as 1.26 m/km, which compares with 0.43 m/km for the Main Perth shoreline and 0.08 m/km for the Main Postglacial shoreline (Cullingford and Smith, 1966; Sissons, 1967a). Using a broad scale and considering well marked and measured features, relative gradients can be postulated for the buried raised beaches as a group. Found within the Perth Readvance limits they must be younger than the beaches associated with that event while at the same time they are buried by the deposits of the Main Postglacial submergence. On this basis measurements along the shorelines of the buried beaches might be expected to produce gradients somewhere between that of the Main Perth shoreline and that of the Main Postglacial shoreline.

For the calculation of the gradients, height-distance diagrams and linear regression equations were developed for each buried beach, or in some cases for sections of each beach. Heights measured along the shoreline were projected on to a plane drawn through the Forth valley and aligned N72°W - S72°E; this line being chosen since it is thought to be the one most nearly at right angles to the isobases as known at present (Sissons, Smith and Cullingford, 1966). Distances from a point close to the western end of each beach were measured from the line and against these, shoreline heights were plotted in height-distance diagrams. (Figure VIII.2, for example, shows all projected heights between Menteith and Cambus.) The values of height and distance were then compared statistically and from the results regression lines and gradients were obtained.

The High Buried Raised Beach.

The High Buried Beach is present between the Menteith Moraine and Thornhill, at Burnbank and between Abbey Craig and Menstrie. These three areas are distinctly separate from each other and because of the distances involved (Fig.VIII.2) it was not considered feasible to draw one regression line incorporating all three sets of data, although, if the three sections are part of the same feature, as is strongly suggested by the stratigraphy and the other elements mentioned, it would be expected that the individual lines would have the same or at least similar gradients. To investigate this 17 measurements from the Menteith-Thornhill area, 10 from Burnbank and 12 from the area east of Stirling were treated as outlined above.

From the initial height-distance diagrams (Figs.VIII.3 and VIII.4) it would seem that there is a definite slope in the western section while at Burnbank and east of Stirling the features vary little from the horizontal. To check this, a series of correlation coefficient tests were carried out. In the Thornhill area the data produced a coefficient of -0.360 while south of the Ochils between Abbey Craig and Menstrie the figure was -0.094. The negative results indicate one variable increasing in value as the other decreases, or specifically, as distance from the point of origin increases the shoreline height decreases, as might be expected from the normal slope of Lateglacial beaches down the Forth valley.

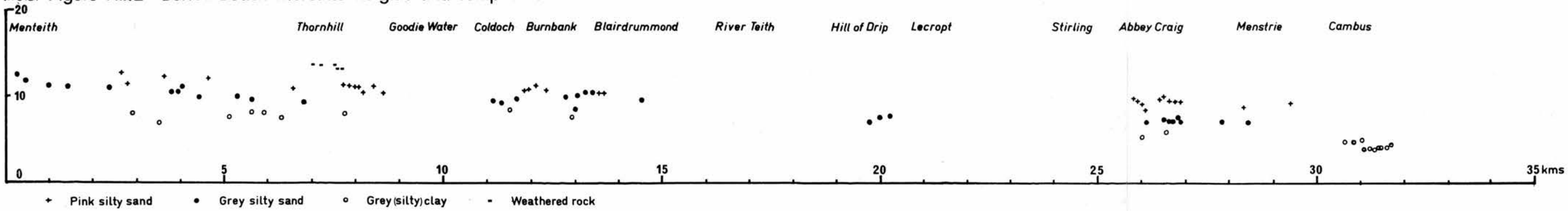


Figure VIII.2 Buried Beach shoreline heights and composition

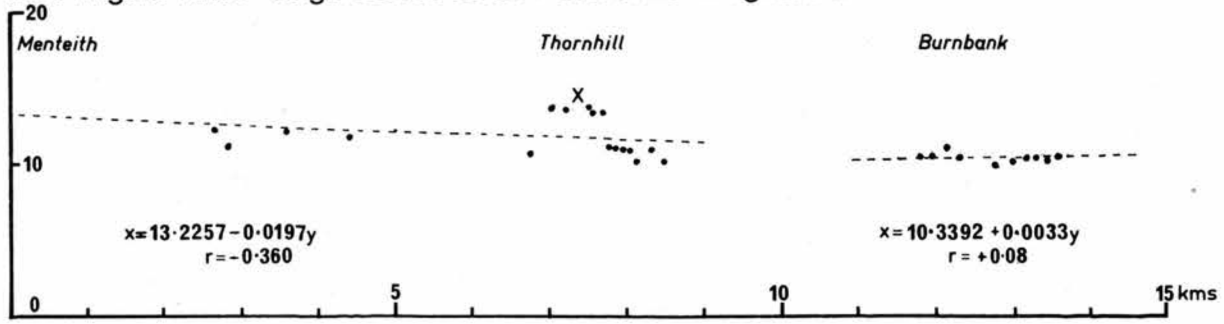


Figure VIII.3 High Buried Beach shoreline diagram 1.

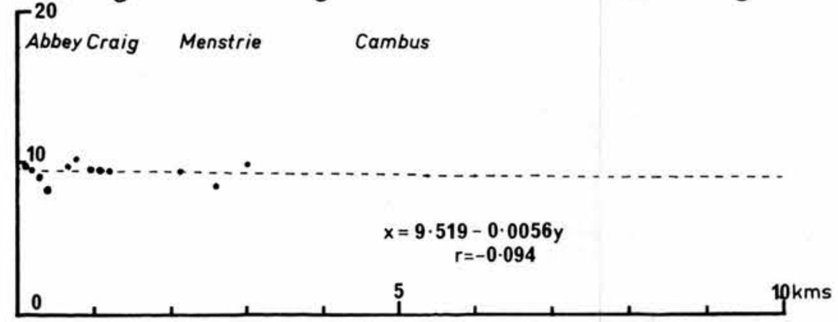


Figure VIII.4 High Buried Beach shoreline diagram 2.

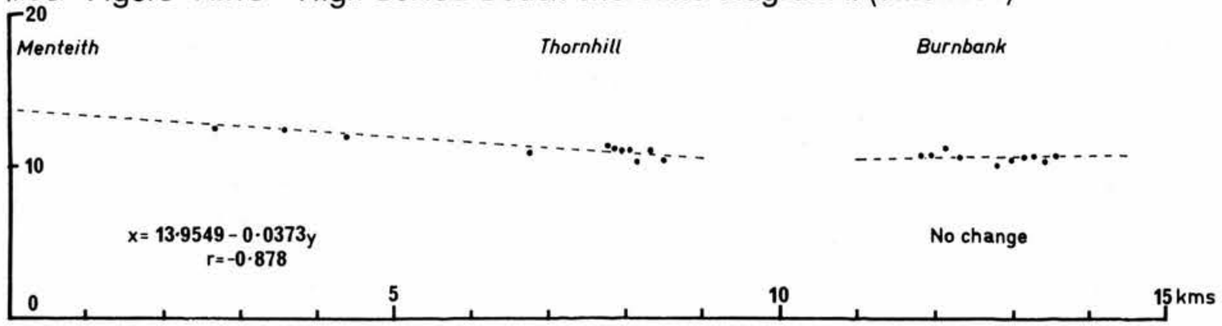


Figure VIII.5 High Buried Beach shoreline diagram 1. (amended)

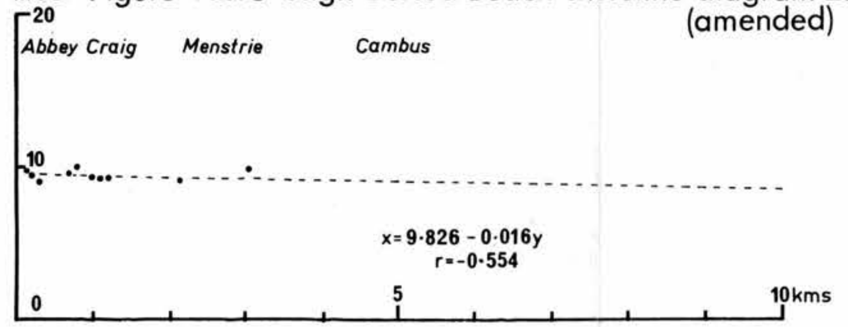


Figure VIII.6 High Buried Beach shoreline diagram 2. (amended)

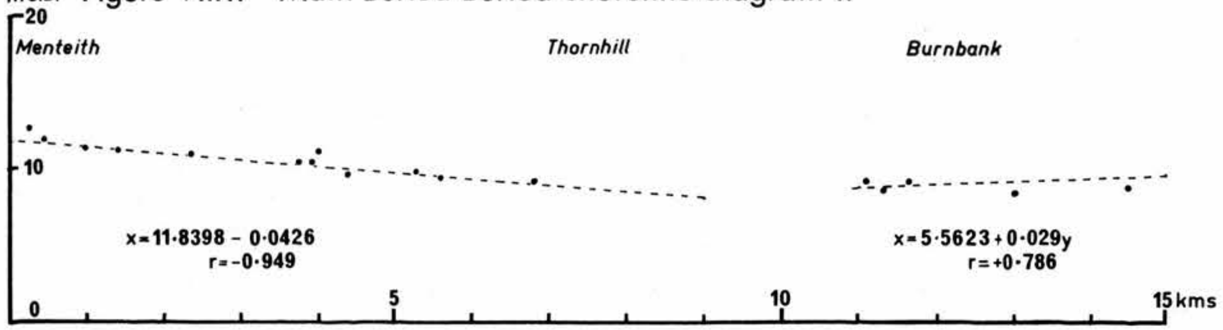


Figure VIII.7 Main Buried Buried shoreline diagram 1.

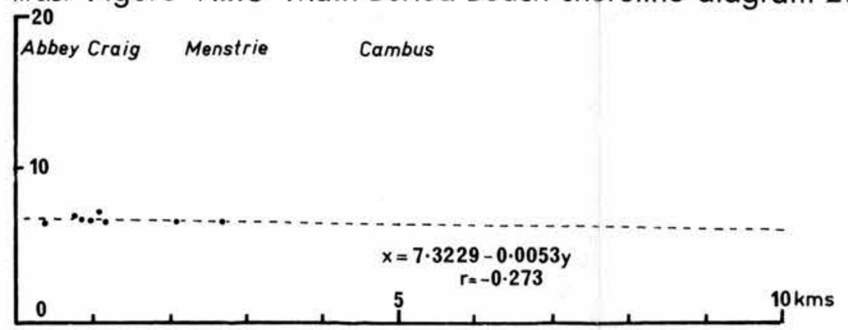


Figure VIII.8 Main Buried Beach shoreline diagram 2.

The third section of beach at Burnbank was found to differ from the other two in that the ten heights in that location showed a positive correlation indicating a rising shoreline downvalley. As was the case east of Stirling, the correlation coefficient was very low, being only +0.078. Such low values were thought to be to a large extent a result of the lack of slope apparent in the height-distance diagrams and regression lines and gradients were determined to examine this further.

For the High Beach in the Thornhill area, a slope of 0.197 m/km was calculated while the corresponding figure for the feature east of Stirling was 0.056 m/km, both slopes being in a downvalley direction. At Burnbank, with the slope in the opposite direction, the figure was 0.033 m/km. Taking the three together, the value at Thornhill is markedly different from the other two, but does fall within the range postulated, being less than half of the slope of the Main Perth shoreline yet remaining greater than that of the Main Postglacial shoreline. On the other hand, while at Burnbank the slope is up to the east and between Abbey Craig and Menstrie it is down in the same direction, an essential fact is that at both locations the beach is not far removed from the horizontal. Thus, it is apparent that the three sections do not completely fit the pattern noted above where all three would have the same or similar gradients.

A fact that cannot be overlooked is the possibility that features of entirely different age are being compared. It is considered, however, that the evidence presented concerning stratigraphy, form and composition is sufficiently strong to outweigh the gradient differences and support their correlation. This being so, the difference in values may be partly explained by slightly different depositional environments in the two areas and in order to examine this some consideration must be given to the formation of the High Buried Beach, for it is felt that this may have some bearing on the results obtained. From an examination of the High Beach on the south side of the Forth, it has been shown that its final formation took place in a relatively short period after the deposition of the main Menteith outwash, but before the ice had finally left the moraine (Chapter I). Although the evidence on the north side of the river does not allow the same precision, it does support a formation at the same time.

The sediments of which the beach is composed were probably provided to a large extent by meltwater streams flowing out from the decaying ice. However, from the colour of the beach, it would seem that a considerable proportion of the material was obtained from the adjacent Old Red Sandstone sediments (and from accompanying volcanics in the case of the Ochils) that must have backed the coastline at the period of formation. Agencies such as marine erosion and deposition from streams flowing into the sea must have provided sediments for the building of the beach, but a further important factor, particularly along the Ochils, may well have been slope wash or slumpage from the slopes behind the beach. The amelioration of climate after the glacial period would provide suitable conditions and this process has already been used to explain the hummocky nature of the High Buried Beach near its backslope (Chapters III and V). If this was so, it would have certain implications as far as the above results were concerned. Firstly, with streams and mass movement providing an abundance of material for the formation of the beach, the relative importance of the sea in determining the form of the shoreline may have been reduced and the net effect of isostatic recovery hidden somewhat. Secondly, the hummocky nature of the beach near its inner edge would make the choice of heighting points very important (Chapter V). Where a beach is visible, some allowance can be made, but the difficulties are increased if it is buried, as is the case with the High Beach.

With differences in gradient such as those existing between the Menteith-Thornhill section on the one hand and the Burnbank and Abbey Craig-Menstrie sections on the other, together with the limited number of heights available, it was thought unlikely that a revision of the points would radically alter the pattern. Nevertheless, the borehole logs and beach profiles were re-examined in an attempt to minimise the possibility of misrepresentation. Where any doubt existed as to the position of a particular spot-height with reference to the shoreline, it was discarded.

The main problem concerned 5 heights (marked X in Figure VIII.3) referring to the sub-carse surface near Thornhill at approximately 13.0 m O.D. The surface consisted of weathered rock or coarse red sand resting upon rock and in the short distance over which it was located it was virtually horizontal. While it could not be linked with any other feature in the area it was not considered to belong to the High Beach. Three additional heights, one near Menteith and two east of Stirling appeared non-representative and were therefore removed from subsequent calculations.

This brought about the reduction of heights to 11 between Menteith and Thornhill and 10 east of Stirling, the number at Burnbank remaining the same. The amended groupings were then replotted on height-distance diagrams (Figs.VIII.5 and VIII.6) and in both cases the general downvalley slope was apparent. In the west, the revision produced a much stronger correlation coefficient at -0.878 and the regression line calculated from it gave a gradient of 0.373 m/km, slightly less than double the original figure. Between Abbey Craig and Menstrie, the correlation was also improved, to a value of -0.554, while the gradient increased to 0.168 m/km from 0.056 m/km, reducing its similarity to the slope of the Burnbank section. These results along with the figures from Burnbank were considered to be the best obtainable from the available data and were used in interpretation and for comparison with results from other buried beaches.

In summary, it can be noted that the High Buried Raised Beach on the northern side of the Forth valley does not exist as a feature with a single gradient applicable to its entire length. It has been shown to consist of at least three sections with different gradients (Fig.VIII.9). The slope is greatest in the west between Menteith and Thornhill where it falls from 12.8 m O.D. near the former to slightly less than 11.0 m O.D. just east of the latter. Beyond the break in the beach at Coldoch, heights close to the lower value are also found in the almost horizontal section at Burnbank. Such a situation suggests that a sharp change in gradient takes place somewhere in the vicinity of Thornhill, the pronounced eastward slope being replaced by one lying close to the horizontal. Downvalley from Burnbank the High Beach is absent as far as Abbey Craig, but the height difference between the two sections allows a gradient to be estimated. Over a distance of 12.0 km the height of the shoreline is reduced by approximately one metre, giving a slope of 0.08 m/km. This compares closely with the slope for the Burnbank area in that both are very low and over the distance between Thornhill and Abbey Craig the slope of the beach is considered to differ little from the horizontal. Beyond Abbey Craig the gradient increases again, but does not approach the value for the section west of Thornhill.

Part of the reason for the changing gradients may involve a variation in depositional environments as has already been suggested with mass movement and sediments from the Devon valley playing a greater part in beach formation along the Ochils than farther west. The same might apply at Burnbank with material being carried into an embayment in the shoreline by the Burnbank Burn. In addition, the possibility of different amounts of uplift in different areas cannot be ignored and with regard to this it can be pointed out that Smith (1968) noted a slight reversal of the gradient of his Postglacial 1 shoreline in the Burnbank area. At this stage, the amount and distribution of heights on the High Beach limits the conclusions that can be drawn, but it appears that the situation is more complicated than at first anticipated and will be considered further when the gradients of the other beaches have been examined.

The Main Buried Raised Beach.

The Main Beach is commonly found lying to the south of the High Beach. For a short stretch at Coldoch, however, the latter is absent and in the Thornhill area the two features are kept apart by the buried valley of the Goodie Water. The most extensive section of the beach is in the west between Menteith and Thornhill with smaller patches at Coldoch-Blairdrummond and east of Stirling between Abbey Craig and Menstrie. In addition an isolated section encircles the rock outcrop of the Hill of Drip.

Shoreline heights from each of these places were examined initially in Figure VIII.2 and by inspection it was apparent that quite marked differences in gradient existed from section to section. In the west, for example, near Menteith there are several points standing in excess of 11.0 m O.D. the highest being 12.1 m O.D. while 7.0 km to the east at Thornhill the lowest altitude is 9.0 m O.D., giving an overall height difference of 3.1 m and indicating a considerable eastward slope. In contrast, between Coldoch and Blair-drummond the altitudinal difference is 1.3 m and it is evident that the surface is sloping in the opposite direction, while in the Abbey Craig-Menstrie area the heights fall into the range 6.6-7.5 m O.D., the shoreline being close to the horizontal. To examine these factors in more detail, the groups of heights were subjected to correlation tests and regression lines were drawn using the techniques already outlined.

For the longest section of Main Beach, west of Thornhill, a total of 12 shoreline heights gave a strong correlation coefficient of -0.949, indicating a downvalley slope. The gradient calculated from this figure was 0.426 m/km (Fig.VIII.7) which does not quite fit the broad pattern noted above since it is the same value as that indicated for the Main Perth shoreline, a considerably older feature, and exceeds that of the High Buried Beach in the same area. With regard to this result, it must be pointed out that over a distance of approximately 4.0 km the Main Beach shoreline has been replaced by the buried valley of the Goodie Water and it was necessary to estimate its height using the general surface level of the beach south of the valley as a guide, projecting it across the valley until it intersected the edge of the High Beach, at which point the height was taken. It is considered that the altitudes produced were reasonable estimations since the surface of the beach departs little from the horizontal in a north-south direction and any slope that does exist is regular (Figs.III.4 and III.5). Five heights were estimated in this way, all towards the eastern end of the feature and despite the precautions taken, any under-estimation of these heights would have the effect of increasing the overall gradient. Nonetheless, while this may allow that particular value of the gradient to be questioned, inspection of the seven western heights on the Main Beach shoreline proper (Fig.VIII.2) indicates that its considerable slope cannot be denied.

The steep slope of the western section ends at Thornhill and from Coldoch to Blairdrummond the shoreline rises at a rate of 0.299 m/km. With only five poorly distributed heights available, however, the significance of this figure is questionable, although it does compare with the slope of the High Beach in the same area, in direction if not in value. The number and location of the heights may partly explain the anomaly and the most easterly two of the five are at points where the beach overlaps the Burnbank and Blairdrummond gravels which may have caused some increase in height. Whatever the cause, it is clear from the more general altitudinal information on the Main Buried Beach that the section between Coldoch and

Blairdrummond must be considered as a separate entity as far as shoreline gradient is concerned.

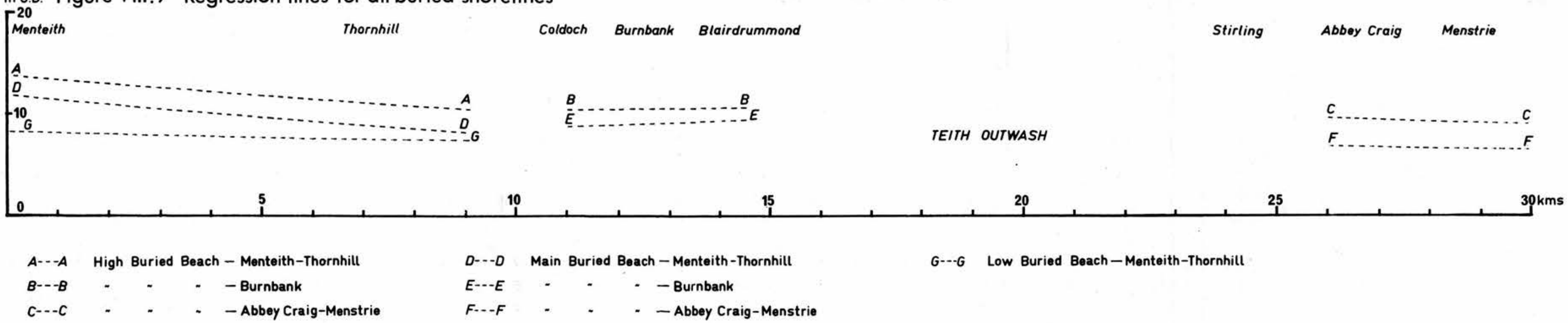
In the other major portion of the Main Beach, east of Stirling, nine measurements along the shoreline gave a height-distance correlation coefficient of +0.298 rather limited in its statistical significance and indicating a rise in altitude of the feature eastwards at a rate of 0.100 m/km. Initially, the depositional activities of the River Devon were seen as a possible reason for this anomalous slope, the addition of material to the eastern end of the beach being sufficiently great to mask the effects of later isostatic uplift. Further examination of the altitudinal data, however, cast doubt on the validity of the first number in the group. At 6.6 m O.D. it was at least 0.4 m lower than any other height and being at the western end of the system might in itself have been responsible for the calculated rise towards the east. To test this a new correlation coefficient was obtained using the eight remaining heights and this gave a value of -0.273, still very low, but indicating an eastward gradient, which was calculated at 0.053 m/km (Fig.VIII.8). With the altitudes involved all falling within 0.5 m of each other and with the second gradient much closer to the situation indicated in Figure VIII.2, it was considered that the result obtained using eight heights was more representative than that produced by the original nine.

Reviewing the information presented above, it is apparent that the steeply sloping shoreline of the section of Main Beach downvalley from Menteith is replaced at Thornhill by a stretch that slopes upwards as far as Blairdrummond where the beach ends against the Teith gravels. Where the shoreline can be identified again east of Stirling, it is found to slope gently eastwards. As was done with the High Beach, an estimation of a gradient can be made to link the sections east and west of the Teith gravels. At Blairdrummond the shoreline averages close to 9.0 m O.D. compared with an average height of slightly more than 7.0 m O.D. between Abbey Craig and Menstrie. Since the distance involved is more than 11.0 km the gradient is approximately 0.18 m/km. With the High Beach it was possible to show that the gradient of the section in the Burnbank area could be considered along with that estimated between Blairdrummond and Stirling since both were close to the horizontal. This is not immediately possible in the case of the Main Beach because of the relatively steep downvalley rise between Coldoch and Blairdrummond. However, some doubt has already been cast on the validity of that result and it is further weakened if the gradient between Thornhill and Abbey Craig is examined. At the former, shoreline heights are very close to those for the Burnbank area and their comparison with heights on the eastern section at Abbey Craig allows a gradient of approximately 0.12 m/km to be estimated. Since this figure is similar to that for the shorter distance between Blairdrummond and Abbey Craig, it is suggested that the result for the Coldoch-Burnbank area is in error, although the possibility of a slight up-gradient to the east cannot be completely ruled out.

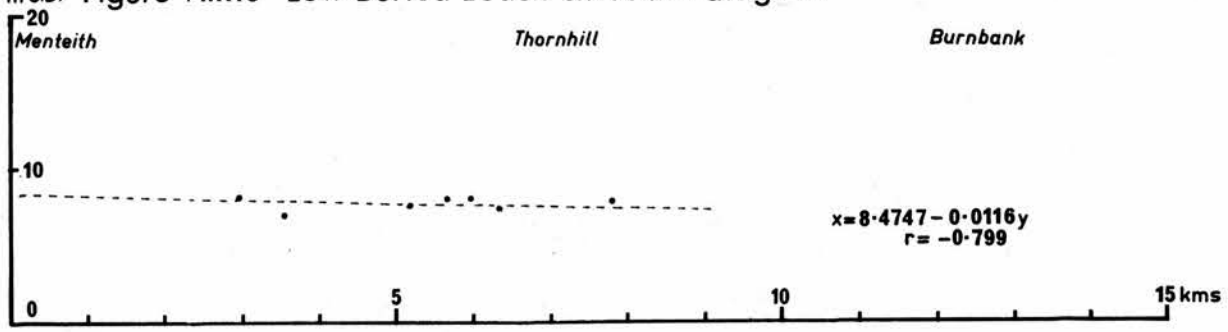
Some additional modification is allowed by three heights on the Main Beach shoreline at the Hill of Drip. At slightly greater than 7.0 m O.D. they are extremely close to the heights available east of Stirling, indicating that between Hill of Drip and the eastern section of the beach, the shoreline is virtually horizontal at a gradient close to 0.03 m/km. As a corollary to this, a change in level must take place between Blairdrummond and Hill of Drip, but unfortunately, with the presence of the Teith gravels and the probable effects of their deposition on beach formation, it has not been possible to locate the changeover more precisely.

To summarize, it is suggested that from Thornhill to a point between Blairdrummond and the Hill of Drip, the shoreline of the Main Buried Beach lies close to 9.0 m O.D., perhaps rising slightly towards the east. Beyond this, through the Hill of Drip to the Abbey Craig-Menstrie area the beach stands at little more than 7.0 m O.D. with only a slight increase in gradient east of Abbey Craig. Thus, between Thornhill and Menstrie, while the shoreline in general lies close to the horizontal, there are noticeable changes in altitude from area to area.

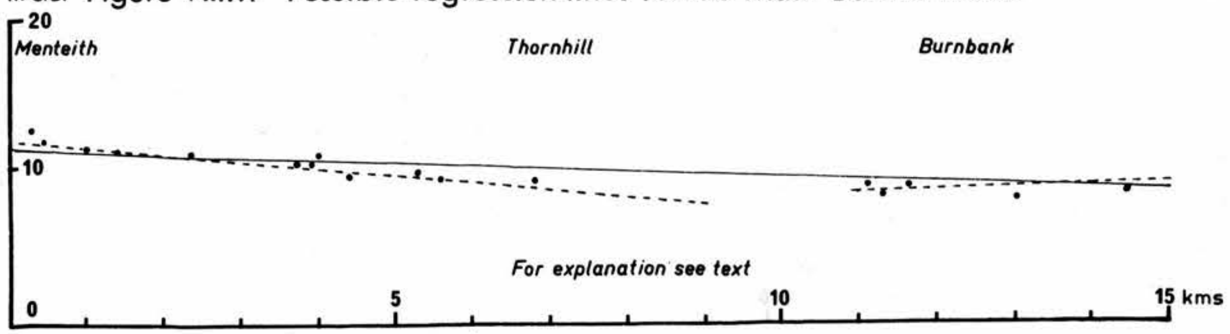
At this stage it is perhaps apparent that there is a certain similarity between the shoreline gradients of the High and Main Buried Beaches in both the overall pattern and in individual sections (Fig. VIII.9). In the west, the shorelines slope relatively steeply down-valley as far as Thornhill where they reach heights close to those measured at Coldoch and Burnbank, indicating a sharp change in gradient that is common to both beaches. From Thornhill eastwards to Abbey Craig the slope of each beach is relatively gentle with a slight reversal of gradient at Coldoch and Burnbank persisting as far as Blairdrummond. Beyond Abbey Craig the gradients increase again, that of the High Beach moreso than that of the Main Beach. The overall relationship appears strong and it is suggested that the separation of the Main Beach into two facets between Thornhill and Abbey Craig m O.D. **Figure VIII.9 Regression lines for all buried shorelines**



m O.D. **Figure VIII.10 Low Buried Beach shoreline diagram**



m O.D. **Figure VIII.11 Possible regression lines for the Main Buried Beach**



will also apply to the High Beach, although it cannot be proved from the information available at present.

Having outlined the close relationship between the slopes of the High and Main Beaches, the case of the Low Beach can now be examined. Although the information here is relatively slight, it might be expected that it would bear some similarity to the higher features. The only area with data adequate for the calculation of a correlation coefficient and regression line is west of Thornhill, where seven heights are available (Fig.VIII.10). These produced a relatively strong correlation coefficient of -0.799 which in turn gave a gradient of 0.116 m/km. With its slope to the east this compares with the two higher shorelines in the area although the actual gradient is much less. Beyond Thornhill at Coldoch and Burnbank two heights stand slightly higher than those of the more westerly group and this might be an indication of the slight rise noted in this area in the other shorelines. East of Stirling the 12 heights that have been measured on the Low Beach shoreline are not sufficiently well distributed to allow any accurate calculation of gradient to be made, although they do suggest that the beach slopes relatively steeply between Abbey Craig and its most easterly location at Cambus. While the gradient of as much as 0.20 m/km estimated for this stretch is considered rather high it may well be indicative of the increase in gradient noted for both the High and Main Beach shorelines in this area. (Since mining subsidence is prevalent in this area, the possibility of it increasing the slope of the Low Beach was considered, but examination showed no evidence that it was of any importance in this particular case.) Because of the limited data it is not possible to elaborate further on the relationship of the Low Beach to the higher pair, but considering the broad similarity that applies to other aspects of the beaches, it is suggested that the distribution of gradients along the Low Beach should not differ radically from that of the other two.

Gradients for the equivalent buried beaches on the south side of the Forth have been calculated or estimated by Sissons (1966, 1967a) and these can now be compared with results from the present study. Sissons found the High Beach in the west to be close to the horizontal while the same feature north of the Forth slopes to the east at a rate of 0.373 m/km. The lack of slope in the south was initially explained by the effects of stream deposition along the shoreline, masking the effects of isostatic tilting. However, numerous streams carry material off the hills behind the carse on the north side also, yet the shoreline gradient is considerable. This does not necessarily disprove the importance of stream action, but it does suggest that it might not have been the sole reason for the relative horizontality of the High Beach south of the Forth. A second estimation for the beach as a whole from Menteith as far as Grangemouth produced a gradient of about 0.2 m/km.

Sissons also calculated a slope of 0.15 m/km for the Main Beach and slightly less for the Low Beach. With a gradient of 0.116 m/km the Low Beach between Menteith and Thornhill fits the pattern, but at 0.426 m/km the slope of the Main Beach shoreline in the same location is almost three times as great as that of its southern counterpart. Attention has already been drawn to the questionable accuracy of such a large value -- it is in fact equal to the gradient calculated for the Main Perth shoreline in the Forth -- but even allowing this, the figures for the High and Low Beaches suggest that a more accurate value would still be greater than 0.15 m/km. Thus, with the exception of the similarity between the Low Beach sections, there appears to be little relationship between the shoreline gradients of the buried beaches on either side of the Forth valley in the west.

One of the main problems in comparing shoreline gradients involves the examination of like features. For example, in the past it has been common to look at shorelines as features with a single gradient continuous over their whole length. The present study has indicated that the buried beaches at least do not conform to this system, but consist of a number of facets along their length, each with a distinctly different gradient. Taking the section of the Main Beach between Menteith and Burnbank as an example, the overall gradient is 0.167 m/km. On dividing the shoreline in two, in keeping with evidence from the height-distance diagram (Fig.VIII.11), the western section gives a gradient of 0.426 m/km while the eastern rises downvalley at a rate of 0.299 m/km, both values markedly different from each other and from the original. It is not valid therefore to compare the gradient of a small section of shoreline with that of the complete feature. This may apply to the comparisons attempted above, for the results produced on the south side of the Forth were obtained between Menteith and Stirling and perhaps represent an average of two or three gradients. Since the buried beaches show the presence of sections with distinctly different gradients along their length, it is possible that other older or younger beaches in the area will do the same and until the presence or absence of such sections can be verified the gradients are not strictly comparable.

While the presence of changing gradients can be recognised relatively easily by inspection, the reasons for their presence are less easily arrived at. It was suggested above that on the High Beach shoreline the reversal of gradient at Burnbank and the relatively low value along the face of the Ochils might be due to depositional conditions along the shore when the beach was being formed, with the abundance of streams and mass-movement carrying sediments into the sea helping to mask the effects of isostasy. It is certain that this type of deposition took place, but its importance in influencing the gradient has to be re-examined in the light of evidence from the Main Beach. The changes in gradient along the shoreline of this beach closely parallel those of the High Beach, while the latter itself normally separates the Main Beach from the source of extra depositional material in the Ochils or the hills behind the carse. This being so it would seem necessary to look for a more fundamental cause. Since the tilting of the shoreline is caused in the first place by isostatic compensation, it is possible that local differences in uplift would produce the variations. This is supported to a certain extent by the Postglacial beaches. For example, Smith (1968) has noted a reversal of gradient in his Postglacial I shoreline at Burnbank, the same area in which the High and Main Beach shorelines rise downvalley, while well away from any peculiarities that the Forth valley might possess, McCann (1966) has pointed out differential tilting of the Main Postglacial shoreline near Loch Linnhe in Western Scotland. At this stage it is not possible to speculate on the reasons for local changes in the amount of uplift, but it is suggested that a closer investigation of the geology or glacial and depositional history of the Thornhill-Burnbank-Blairdrummond area, where the changes are most obvious, might provide some of the initial answers.

CHAPTER IX

RELATIONSHIPS BETWEEN THE BURIED BEACHES AND FEATURES OR EVENTS BEYOND THE FORTH VALLEY

The buried raised beaches and associated landforms have little surface expression at the present time, yet it has been shown that they are major features in the geomorphological development of the Forth valley. Together they underlie more than 50 sq km of the carse-lands and represent some 3,500 years of depositional and erosional activity before their burial beneath several metres of carse-clay during the Postglacial transgression.

The study of the buried beaches has revealed considerable oscillations of sea-level during the period of their formation and this provides a point from which some wider relationships may be examined. It is generally accepted that during the last several thousand years world sea-level has varied largely as a result of the after effects of the last major glacial period, the level rising as water, previously trapped on land in the form of ice, melted and returned to the ocean or falling when land ice periodically reasserted itself. Expressed in these terms, no account is taken of local variations that might alter that simple relationship and it is suggested that an examination of the situation in the Forth and its comparison with the overall pattern might allow some estimate to be made of the extent and importance of local conditions on sea-level change in this particular case.

In addition, the buried beaches of the Forth are part of a distinct stratigraphical sequence that includes the carse-clay of the Postglacial transgression and if features comparable to the buried beaches are present elsewhere in Scotland a probable location would be in association with the carse-clay. While the latter has been examined by numerous workers since the second half of the 19th century (Chapter I), information on the sub-carse deposits remains extremely limited, restricting any comparisons that might be attempted from area to area. However, the evidence from areas of carse-clay outside the Forth has been considered below and possibilities for further investigation have been outlined.

Sea-level change.

The multiplicity of articles that have risen out of the widespread evidence of sea-level change often possess an exactitude that is more apparent than real. Part of the problem rests with the initial evidence, for despite its extent it is often in a form unsuitable for interpretation or quantification, but the nature of the change itself poses even greater difficulties. Total sea-level change depends upon several factors working together in such an integrated fashion that individual effects cannot be readily separated from the whole, while the relative importance of the various components changes with location and with time. These components fall into two groups, namely, those causing upwarping or downwarping of land and those producing eustatic changes of sea-level. In the former may be included the deformation of coastal areas by tectonic downwarping as in the case of the Netherlands and Southern England, the change in isostatic balance produced by large scale erosion of the landscape and redistribution of sediments, and glacio-isostatic movements. The latter include changes in the form of ocean basins, the displacement of water by sediments, changes in volume of sea-water with changing temperature and variation in the amount of water retained on land in glaciers and ice-sheets (West, 1968). Most of these factors are difficult to quantify with any great accuracy, but it is often possible to estimate their relative importance in time and place. During the period and in the area with which the present study is concerned for example, it is normally considered that the most important element in determining the relative level of land and sea has been the combined effect of the eustatic and isostatic movements produced by glaciation (Walton, 1966). The separation of these two components is not without problems, but by comparing the varying positions of land and sea in the Forth valley with calculated world-wide eustatic changes it should be possible to estimate the relative importance of the isostatic and eustatic elements in the formation of the buried beaches.

Various workers in recent years have been concerned with eustatic movements in specific areas or in the world as a whole (Bennema, 1954; Shepard and Suess, 1956; Godwin, Suggate and Willis, 1958; Curray, 1965; Segota, 1968) and their results have been summarised by Jelgersma (1966) and Guilcher (1969). Despite the fact that many of these researchers have used similar methods and have considered results from the same areas, there is little overall agreement on recent changes in sea-level and Jelgersma (1966) has noted that it may never be possible to construct a good curve of eustatic changes during the Postglacial period. Major problems arise from the quantity and quality of the data and from individual interpretation of the various factors influencing sea-level change. In most cases, for example, radio-carbon dates from deposits overwhelmed by the rising sea have been utilized in the production of a curve, but the fact that few of the dates have been obtained with sea-level change as a specific objective has caused difficulties in interpretation. Furthermore, in order to isolate eustatic changes in level from isostatic and tectonic influences the dates must pertain to areas of relative stability in the earth's crust. Fairbridge (1961) attempted to satisfy this requirement in drawing up his curve, but others such as Shepard and Suess (1956), Godwin, Suggate and Willis (1958) and Segota (1968) used dates obtained from such areas as the Mississippi delta and the Netherlands where local tectonic movements or the compaction of sediments must surely affect the final results. While some allowance can be and has been made to compensate for the non-eustatic variations, there remains less likelihood of error if results from stable areas are used where possible. However, as Jelgersma (1966) has pointed out, "even then the results are questionable since it is hard to believe in the stability of any area of the world".

Considering these points, it must be apparent that there may be considerable imprecision in most (if not all) curves of eustatic change and this may account for the variety of positions and forms of the curves reproduced in Figure IX.1. Contrasting with this is the relative accuracy possible when considering isostatic changes which may be obtained from the results of accurate levelling. In combining the two factors - isostasy and eustasy - in order to relate local variations in sea-level to the world-wide pattern, much will depend upon the choice of eustatic curve. That produced by Fairbridge (1961)

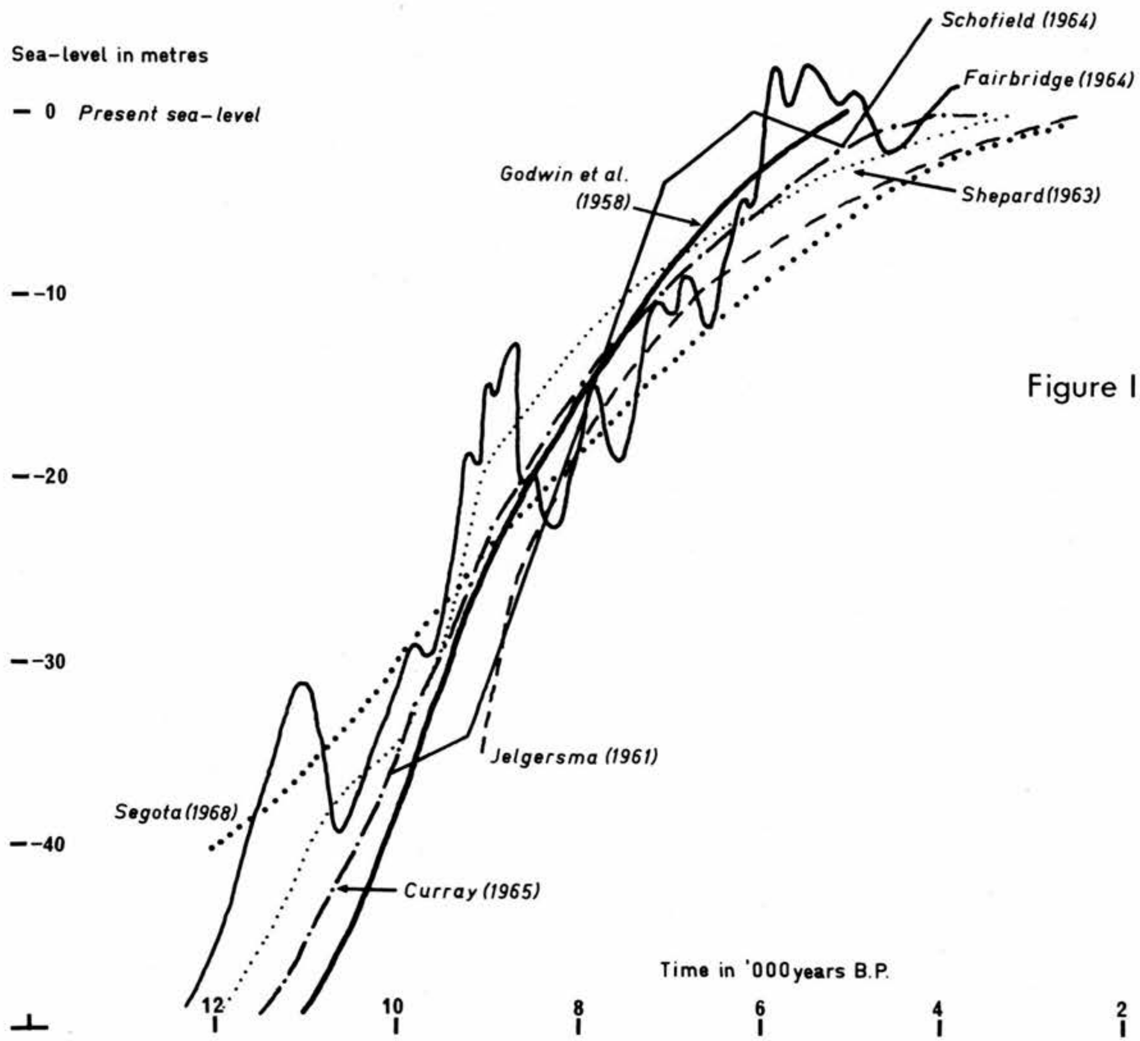


Figure IX.1 Several recent interpretations of eustatic change appears to be most comprehensive and the fact that it is not a smooth curve, but attempts to indicate short term fluctuations, may seem to imply a considerable degree of accuracy. The latter has been questioned by a number of writers, however, (Jelgersma, 1966; Shepard and Curray, 1967; Guilcher, 1969) and certainly in places Fairbridge's curve is relatively far removed from the others (Fig.IX.1). This is particularly true from 6,000 B.P. onwards where Fairbridge shows an oscillating sea-level at times above the present level, while other curves, although differing in the exact date at which the present level was reached, do not rise above it. Of greater consequence in the present study is the discrepancy that exists between 9,200 and 8,600 B.P. where the Fairbridge curve peaks quite sharply and stands between 4.0 and 13.0 m higher than the others. Since the Low Buried Beach was formed during this period, the choice of curve could have a significant effect on the results obtained for variations in level in the Forth valley. It appears that Fairbridge's sea-level for this period is too high, yet there is a considerable range offered by the other curves. Indeed, none of the curves has escaped criticism and the problems have been summarised by Jelgersma (1966) and Guilcher (1969). For the most part the criticisms mention inadequate data or the possibility of tectonic or some other activity affecting the assumptions necessary for the compilation of those data. Most writers accept the inadequacy of present results and point out the need to improve measuring and dating techniques. Any conclusions based on such results must therefore be kept in perspective and this applies to the present study where changes in level cannot be estimated without some indication of world-wide sea-level in the past, however inadequate the latter may be.

Fairbridge's results have already been used in the Forth valley (Sissons, 1967a) in examining changes in level associated with the older Lateglacial raised beaches in East Fife, and the Perth Readvance beaches. For this reason, an attempt was made initially to link the buried beaches with the same curve. From the morphological and stratigraphical evidence it is apparent that the earliest of these features -- the buried gravel layer -- was associated with a period of low, but rising sea-level during which extensive erosion took place. This rise of the sea relative to the land culminated shortly after the readvance of the ice to Menteith and the High Buried Beach was produced. Subsequently, a net fall in sea-level took place with two distinct reversals of the trend bringing the Main and Low Beaches into being. Following the formation of the latter, the downward trend continued and the sea was confined for a short period to the buried estuary of the Forth before rising again in the major Postglacial transgression.

These events took place within a period between about 12,000 and 5,000 B.P. and the relative changes in sea-level have been reproduced in Figure IX.2. Because of the sloping nature of the shorelines, the graph can represent changes at only one point in the area and for present purposes a location immediately east of Abbey Craig was chosen. This gave a complete suite of buried beaches, at the same time allowing a reasonable estimation of the altitude of the buried gravel layer. It was noted in Chapter V that certain patches of gravel lying in the vicinity of the Forth, east of Stirling, could be considered to represent the buried gravel in that area. The

Figure IX.2 Relative sea-level changes at Abbey Craig

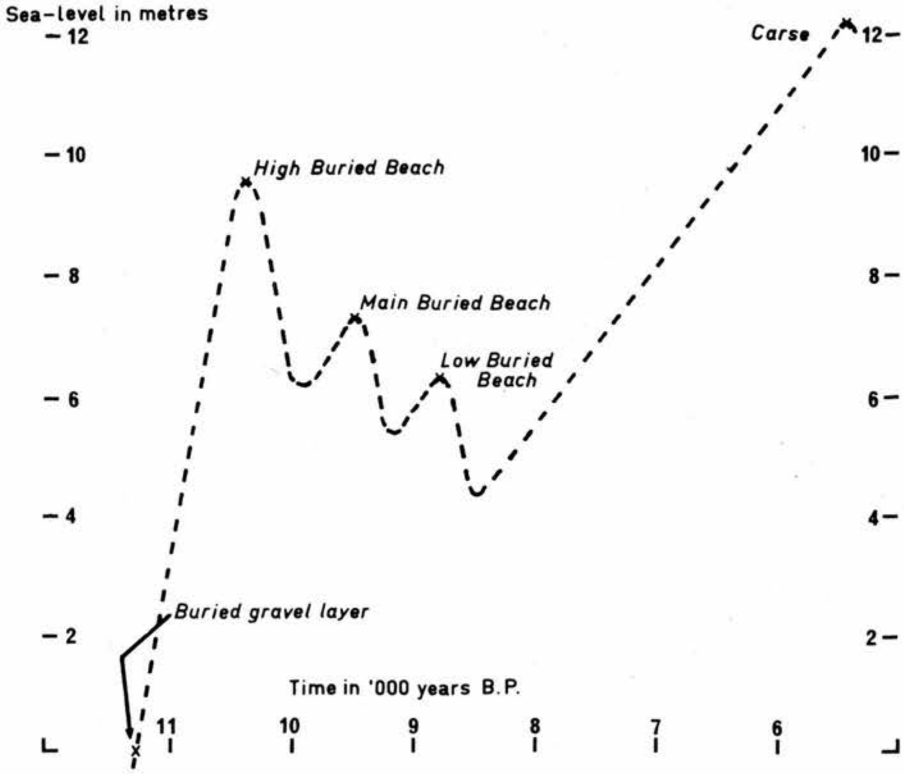
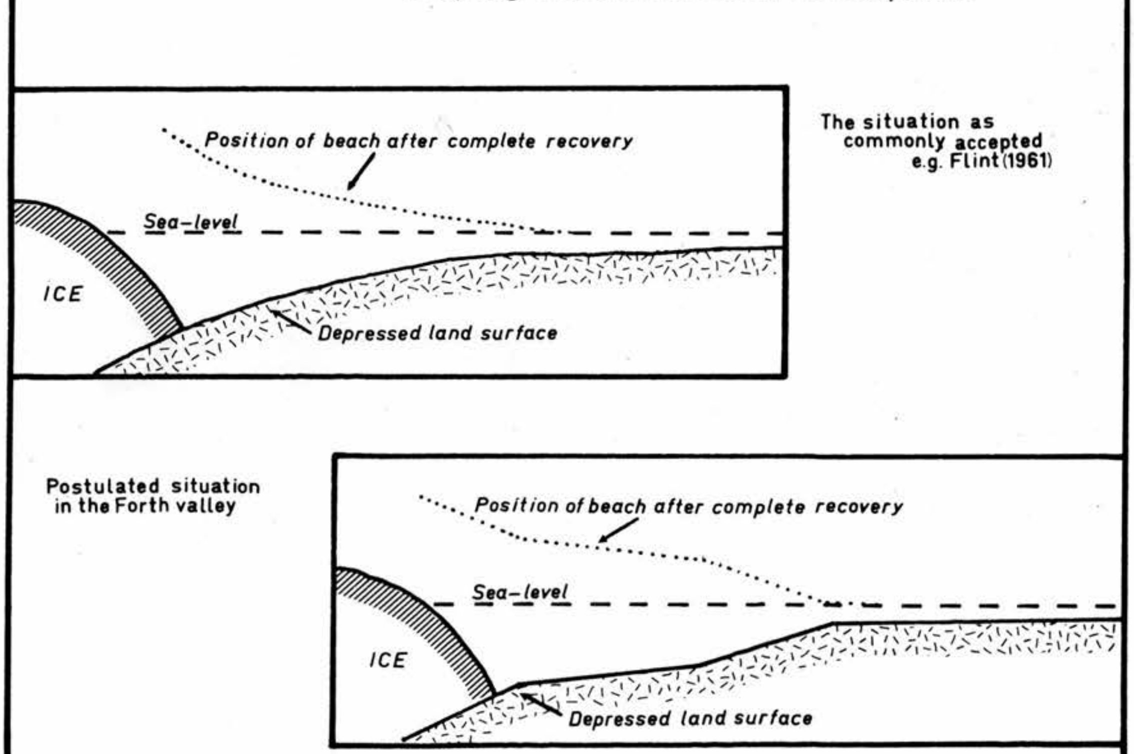


Figure IX.3 The effect of different forms of crustal warping on raised beach development



altitude of the surface of each of these sections lay close to Ordnance Datum and that altitude was used in calculations involving the gravel layer. Unfortunately, no shoreline measurements are available for the buried gravel in this area and there is no shoreline gradient from which they may be estimated. At the same time, the gravel surface shows a considerable altitudinal range in other parts of the Forth, while the date of its formation is less precise than that calculated for any of the other features. Thus, the results obtained using the buried gravel layer must be recognised as likely to be less accurate than those produced from the buried beaches.

The total curve can be divided into three sections, two of which indicate a steady rise in sea-level separated by a third where there is a net downward trend. While the two rising sections have a similar form they have different causes. From approximately 8,500 to 5,500 B.P. the sea-level rose steadily as a result of the final stages of the world-wide decay of ice that followed the last glaciation. In the second case, the rise of the sea relative to the land that began sometime before 11,500 B.P. and culminated about 10,300 B.P. can also be related to glaciation, but in a different way. In part, this earlier rise coincided with the Loch Lomond Readvance producing the apparent anomaly of a rising sea-level while water was being retained on land in the form of ice. Such a situation is explicable in terms of glacio-isostasy, the depression of the land beneath the expanding ice producing an apparent rise in sea-level. While the Stirling area was not covered by ice during this Zone III Readvance, it was sufficiently close to the ice mass to experience the effects of downwarping. This explanation can be applied to the period from about

10,800 B.P. onwards when the ice began to accumulate, but it is possible that the earlier part of the rise may have been eustatically produced as water freed from glaciers and ice-sheets after the earlier Perth Readvance (and its equivalents elsewhere in the world) finally overhauled the isostatically rising land. Thus, the overall rise in sea-level between 11,500 and 10,300 B.P. may well have been due to more than one cause and, in fact, may have been less regular than indicated by the present curve.

The third section of the curve is characterised by a net downward trend from a high of 9.5 m O.D. at 10,300 B.P. to a low of 6.3 m O.D. at 8,800 B.P. It seems likely that the level was lower than 6.3 m both before and after 8,800 B.P., but by how much cannot be calculated at present and the figure of 3.2 m for the overall fall can only be a minimum. These values give an average lowering of the sea relative to the land of 0.21 cm per year. At the same time, an examination of Fairbridge's curve of eustatic changes for the same period, (Fig.IX.1), shows that world-wide sea-level was rising at an average rate of 1.6 cm per year. Since the rise is not duplicated at Abbey Craig, non-eustatic factors must have been sufficiently strong to obscure the trend. As already indicated, the most important non-eustatic factor in the area concerned is glacio-isostasy and its relative importance is apparent from a simple comparison of the two curves.

From the same curves it is possible to calculate the amount of uplift that has taken place. When the High Beach was formed, for example, the sea stood at approximately 39.0 m below its present level, yet the beach is now at an altitude of 9.5 m O.D. close to Abbey Craig, indicating a displacement of 48.5 m in the 10,300 years since it was formed, at an average rate of 0.47 cm per year. This may be illustrated further by reference to the Low Beach which stands at 6.3 m O.D. near Abbey Craig. When it was formed some 8,800 years ago, the sea-level was 15.0 m below the present level, according to Fairbridge. Thus, since its formation there has been 21.3 m of uplift, at an average rate of 0.24 cm per year, or almost half the overall rate since the High Beach was formed. A changing rate of uplift such as this has been recognised frequently and it is commonly considered that the most rapid uplift took place immediately following the decay of the ice and has been slowing down gradually since then (Chapter VIII). However, the isostatic compensation calculated from the buried beaches does not appear to fit that pattern.

In the period between the formation of the High and Main Buried Beaches world-wide sea-level rose by 10.0 m and since the High Beach was not covered that figure must represent a minimal amount of uplift for that period. Furthermore, the height differential between the two beaches is 2.2 m which must have been achieved prior to the building up of the Main Beach, both having undergone the same rate of uplift since then. As a result, the amount of isostatic compensation in the 800 years between the formation of the two beaches must have been at least 12.2 m, or 1.53 cm per year. From Fairbridge's curve the rate of eustatic rise for the same period can be calculated at 1.25 cm per year. In the same way, isostatic uplift between the formation of the Main and Low Beaches took place at a minimum rate of 2.14 cm per year compared with a eustatic rise of 2.0 cm per year.

According to this evidence, uplift in the period between

10,300 and 9,500 B.P. was less rapid than in the years between 9,500 and 8,800 B.P. This is directly contrary to recent results from other parts of the world such as Scandanavia (Lundqvist, 1965) and Arctic Canada (Andrews, 1968) as well as the Forth valley itself (Sissons and Smith, 1965a) all of which show a rapid rise of the land on the initial decay of ice followed by a gradual reduction in the rate with time. In the case of the buried beaches, since the High Beach was formed first and at a time when ice was still at the moraine, the rate of uplift following its formation would be expected to be greater than that following the Main Beach. An explanation of this situation might be pursued in the morphology or glaciology of the area, but since the results are so much at variance with the generally accepted facts, the data themselves might be questioned. To check this, rates of uplift were estimated at Burnbank and at Menteith-Thornhill for the same periods, the results being indicated in Table IX.I.

TABLE IX.I

Average rates of isostatic uplift (in cm/yr) calculated using Fairbridge's (1961) curve of eustatic change

	10,300-9,500	9,500-8,800
Abbey Craig	1.53	2.14
Burnbank	1.45	2.14
Menteith-Thornhill	1.50	2.28

It can be seen that the results support each other and show that throughout the area covered by the buried raised beaches, the rates of uplift were comparable despite a distance of approximately 22.0 km separating the Abbey Craig and Menteith-Thornhill locations. This suggests that the initial results from Abbey Craig were not due to discrepancies peculiar to that area.

Since all the results were based on values of a rising sea-level obtained from Fairbridge's (1961) curve, this was also checked. It was noted above that in the period between 9,200 and 8,600 B.P. that curve gave results considerably greater than those of the other workers (Fig.IX.1) and this could have influenced the uplift figures since the Low Beach, upon which they were partly based, was formed during this period. To test this, further rates of uplift were estimated using other curves of eustatic change.

After Fairbridge, perhaps the most comprehensive curve is that of Shepard (1963) and this has been used in the calculation of isostatic rebound in Arctic Canada (Andrews, 1968, 1969; Andrews, Buckley and England, 1970). Using the results from the buried beaches it was estimated that between 10,300 and 9,500 B.P. the rate of uplift at Abbey Craig was 1.03 cm per year while between the latter date and 8,800 B.P. the rate was reduced to 0.86 cm per year which fits in with the generally accepted pattern of uplift. These results together with rates of uplift calculated from other curves have been presented in Table IX.II below.

TABLE IX.II

Rates of uplift (in cm/yr) at Abbey Craig, calculated using different curves of eustatic change

		10,300-9,500	9,500-8,800
Fairbridge	(1961)	1.53	2.14
Shepard	(1963)	1.03	0.86
Godwin	(1958)	1.52	1.43
Curray	(1965)	1.40	1.29
Segota	(1968)	1.03	0.71

It is evident from these results that a considerable range of values exists for each time period, but it is also apparent that all except those based on Fairbridge's curve indicate less rapid uplift between 9,500 and 8,800 B.P. than in the earlier period. With this in mind, it is suggested that for the particular time period under consideration, Fairbridge's results do not give a sufficiently accurate indication of the position of world sea-level to allow a reasonable estimation of isostatic rebound. Among the values obtained from other curves, however, there is considerable variation and which is most accurate is not immediately clear. On present evidence, the hypothesis of a steadily rising sea-level reaching its present position only relatively recently and supported by the curves of Shepard (1963) and Segota (1968) appears reasonably acceptable (Jelgersma, 1966). It is suggested therefore that the results obtained using either of these two curves may be taken as indicative of the rates of isostatic recovery at Abbey Craig.

To complete an examination of the rates of isostatic and eustatic change associated with the sub-carse features, the buried gravel layer must be examined. From the graph of sea-level changes at Abbey Craig (Fig.IX.2) it is apparent that a substantial rise in sea-level relative to the land took place between the formation of the buried gravel layer and the High Buried Beach. Between these features at present there is a height difference of 9.5 m and it may be noted that this must have been achieved by the time the High Beach had been formed since both were subsequently affected by the same amount of isostatic rebound. Thus at Abbey Craig, between 11,300 and 10,300 sea-level made a vertical gain of 9.5 m over the land. On comparing this with Shepard's (1963) curve (Fig.IX.1) it can be seen that during the same time period, world sea-level rose by only 8.0 m. This being so, the additional 1.5 m gain at Abbey Craig could have been produced by depression of the land accompanying the build up of the Loch Lomond and Menteith ice. This figure may appear low and other curves allow estimates of between zero and 9.0 m depression, but it is suggested that all results are relatively inaccurate due to the general problems in the drawing of the eustatic curves along with the difficulties of obtaining comparable heights and dates for the buried gravel layer. However inaccurate it may be, the result is not unexpected and fits in with the concept of crustal depression accompanying even relatively minor glacial readvances.

After the formation of the Low Buried Beach, sea-level fell for a short period before beginning the rise that produced the Main Postglacial transgression. The similarity between this and the rise that brought the formation of the High Beach has already been noted (Fig.IX.2). Differences exist, however, for the earlier rise appears to have been produced, in part at least, by a depression of the land. During the Postglacial rise it can be shown that both land and sea were rising, the latter more rapidly than the former. The difference in altitude between the Low Beach and the main carse surface at Abbey Craig is 5.9 m and this must have been present by 5,500 B.P. when the carse was formed. At the latter date world sea-level stood at -4.5 m O.D. according to Shepard (1963) therefore the surface of the Low Beach would have been at an altitude of -10.4 m O.D. Since world sea-level stood at -20.0 m O.D. when the Low Beach was formed, isostatic recovery must have been 9.6 m in the 3,300 years between 8,800 and

5,500 B.P., a rate of 0.29 cm per year.

In summary, it can be noted that following the depression produced by the ice of the Loch Lomond Readvance, the land at Abbey Craig began a recovery that continued for at least 5,000 years at a gradually decreasing rate.

The results considered above refer only to conditions in the vicinity of Abbey Craig and to supplement them, rates of uplift were estimated farther west at Burnbank and Menteith-Thornhill (Table IX.III).

TABLE IX.III

Average rates of isostatic uplift (in cm/yr) in the Forth valley

	10,300-9,500	9,500-8,800
Menteith-Thornhill	1.51	1.17
Burnbank	1.48	0.88
Abbey Craig	1.03	0.86

These were based only on evidence from the three buried beaches and the buried gravel layer was not considered, but it can be seen that slight differences exist from area to area. The most westerly location -- Menteith-Thornhill -- has experienced more rapid uplift than the more easterly areas during both time periods. While the variations are small the pattern does correspond to conditions indicated by values of contemporary uplift in north-west Europe which show that the rate of isostatic recovery increases towards the location of the centre of the former ice-mass (West, 1968). All three sites in the Forth lie outwith the limit of the Loch Lomond

Readvance, but, being closest to the former ice margin, the Menteith-Thornhill area would have experienced more rapid uplift than Burnbank or Abbey Craig and this is confirmed by Table IX.III.

This more rapid and presumably lengthier recovery in areas of greater displacement is commonly used to explain the tilting of raised beaches with the greater altitudes found close to the former ice margin. This appears to be the case in the Forth valley, for altitudes on the buried beach shorelines near the former location of the ice at Menteith are greater than those east of Stirling, but the changing gradients of the beach shorelines noted in Chapter VIII raise problems. It is common practice to cite a single gradient for the whole length of a shoreline, (although recently Andrews, Buckley and England (1970) have indicated the presence of curved rather than rectilinear shorelines in Arctic Canada) but it was shown that this could not be applied to the buried beaches, each of which included local variations in gradient. It was suggested that this phenomenon was produced by differences in uplift from place to place in the Forth valley and this may well apply, although it cannot be confirmed from the results quoted above. It is also possible, however, that the initial displacement of the surface by glaciation was not in the form of the smooth curve commonly used to illustrate the situation (Flint, 1961), but rather a line consisting of a number of facets showing sharp rather than gradual change in the amount of displacement away from the ice margin (Fig.IX.3). The gradual recovery of these sections at different rates and for different lengths of time, could then be used to explain the variation in gradient along any one or all of the beaches.

Some support for such a development is provided from Fennoscandia, where Sauramo (1958) noted sharp changes in the slope of some shorelines. These were attributed to differential movement along hinge-lines in the earth's crust and suggested that recovery after glaciation was not simply a process of regular updoming. Fairbridge (1961) pointed out that such hinge-lines are common in the early stages of isostatic rebound with no less than four being present in certain Finnish beaches formed between 10,000 and 9,000 B.P. As yet, the concept has not been shown to apply to the Scottish raised beaches, but it is suggested that a closer investigation of the geology or glacial and depositional history of certain parts of the Forth valley might provide some clarification of the local situation while a search for buried beaches (or their equivalent) in adjacent areas could lead to the development of shoreline diagrams and isobases that could be examined for further evidence of the presence or absence of hinge-lines.

Stratigraphical comparison.

The relationship between the carse-clay and the buried raised beaches in the Forth has already been described and the possibility of similar relationships existing in other areas where carse-clay is present has been suggested. This will now be examined further.

North of the Firth of Forth, carselands are found in the Carse of Gowrie stretching along the north side of the Tay estuary from a point near Dundee as far as Perth. On the south side of the river near Abernethy a tongue of carse extends up the valley of the River Earn, a tributary of the Tay. The typical stratigraphy of these carselands has long been recognised (Buist, 1841; Chambers, 1848;

Jamieson, 1865; J. Geikie, 1906) and includes elements, such as the carse-clay itself and buried or submerged peat, that are commonly found in the Forth also. The similarity is confirmed from two sites in the Earn where buried peat has been dated at 8421±157 and 8354±143 years B.P., both directly comparable with a result of 8421±157 B.P. for peat in a similar location at Airth, near Stirling (Godwin and Willis, 1961). Most of the early investigators in the Tay, however, were content to note the stratigraphy as far down as the buried peat, often describing it in some detail, but considered the deposits beneath the peat in only a very general way. J. Geikie, for example, in 1906 mentioned an ancient land surface, well preserved in the valleys of the Tay and the Earn, represented by a thick layer of woody peat from which rootlets passed down into the underlying "fluviatile alluvia" which he appears to have considered as part of the 100 foot raised beach clays. It can be noted that the presence of rootlets passing from the buried peat into the deposits of the Low Buried Beach has already been described for the Forth (Chapter III) while the term "100 foot raised beach clays" as used at that earlier time must have encompassed a great variety of deposits and it is suggested that Geikie's "fluviatile alluvia" represented, in part at least, buried beach sediments.

Other workers have mentioned the presence of a landscape on which the buried peat originally grew (Buist, 1841) or implied the presence of a relatively level surface upon which the peat rested (Jamieson, 1865), but the composition of the feature beneath the peat has not been considered in anything but very general terms. Jamieson used the term "glacial-marine beds" for the deposits while Chambers

(1848) introduced slightly more detail in describing a section near Polgavie in the Carse of Gowrie. The section as a whole consisted of 20 feet (6.1 m) of carse-clay resting upon 4 feet (1.2 m) of peat, the latter containing remains of alder and birch with some still in the positions they had occupied while growing in the blue clay beneath the peat. The clay may represent Lateglacial marine deposits, but in the Forth at least they are seldom found with peat resting upon their surface. Again, although the buried beaches of the Forth are never blue in colour, rather they are grey, some allowance can perhaps be made for individual interpretation where colour is concerned. Comparing the stratigraphy of the two areas it is suggested that the Polgavie peat is resting upon buried beach sediments.

More recently, Sissons, Cullingford and Smith (1965) noted the stratigraphy in a valley cut in Lateglacial marine deposits near Glencarse in the Tay estuary and described the following succession: -

3. Carse clay
2. Peat
1. Fine sand

The fine sand was found to be contiguous with the local Lateglacial beach sediments and since no deposits intervened between the peat and the fine sand it was concluded that the valley was not transgressed by the sea until the carse was laid down. From the point of view of the present study, however, a borehole put down close to the mouth of the valley is of particular interest for it indicated the presence of 1.8 foot (0.55 m) of "soft silty clay" immediately beneath the peat, its surface at a height of 4.8 m O.D. It is considered that this might be the innermost edge of a buried beach.

A similar stratigraphical sequence to that in the Tay has been described for the South Esk at Montrose in Angus (Howden, 1870) and the mouth of the River Ythan in Aberdeenshire (Jamieson, 1865), but apart from the Forth and Tay areas, the distribution of the carselands in the east is quite limited. In the west, however, there are two additional areas that merit examination -- namely, the Solway Firth and the Firth of Clyde.

In the Solway, the carselands have stratigraphical elements directly comparable to those already described in the Forth and Tay. Remnants of formerly extensive surface peat are present, for example, in Lochar Moss and the Moss of Cree, both of which rest upon the silts and clays forming the carse in this area (Jardine, 1964). The comparison can be taken further in a number of areas, for buried peat has been located and dated by radio-carbon assay in a number of sites along the Scottish coast of the Solway. Since the work has been undertaken in most cases with the intention of obtaining a date for the onset of the Postglacial transgression, the results are not always directly related to the underlying deposits with which the present study is concerned. However, the collection of the peat for dating usually exposed the adjacent stratigraphy and this can be examined and utilized for comparative purposes.

Beyond the surface peat, carse-clay and buried peat, comparison becomes more difficult because of the variety of deposits present. Of the more recent sites examined (Godwin and Willis, 1960, 1961, 1962; Jardine, 1964; Godwin, Willis and Switsur, 1965) only one, at Redkirk point near the head of the Firth, has a succession that includes deposits directly analogous to those that form the buried beaches in the Forth. Using the site description, the stratigraphy can be outlined as follows: -

7. Carse clay
6. Peat
5. Sandy grey clay
4. Thin bands of peat
3. Ferruginous sand
2. Glacial Till
1. Rock

The upper peat has been dated at 8135±150 B.P. (Godwin and Willis, 1962) and the lower at 10,300±185 B.P. (Godwin, Willis and Switsur, 1965). From the succession itself, the upper peat, sandwiched between 3.7 m of carse-clay and 2.7 m of sandy grey clay, might well have been considered to represent a lens of vegetable matter included in the carse as the latter was forming, the date indicating its very early incorporation. Comparison with the other elements, however, along with the date of the lower peat does not allow this interpretation and it is suggested that the sandy grey clay is the equivalent of certain of the buried beach sediments of the Forth. With its surface at about 3.0 m O.D. it is lower than any of the Forth features, but greater distance from the centre of maximum isostatic uplift would largely explain this. From the bracketing dates provided by the peat layers the sandy clay must have been deposited at the same time as the Main and Low Beaches, but the dating is not exactly coincident. This in itself presents no real problem at this stage, for local conditions in the Forth and Solway, while broadly similar must have differed in detail and with only one exposure of any consequence from the Solway, the comparison can only be general.

Moving north into the Clyde the sediments of the Postglacial beaches also hide buried peat layers. Recent examples in the lower Clyde in Ayrshire have been examined by Jardine (1964). Only one of the successions described bears any obvious relationship to the situation in the Forth. At Enoch Farm, near Girvan, a thin band of buried peat resting upon 1.1 m of laminated clay was dated at 9362±150 B.P. Considering the type of deposit and its age, along with the fact that it lies at approximately 5.0 m O.D., the laminated clay may well be related to the buried beaches. A date of 9020±150 B.P. from buried peat in a second site at Girvan is close to the original as are the figures of 9620±150 and 9530±150 B.P. from Irvine, along the coast to the north. In each of these cases, however, the stratigraphy bears no obvious similarity to that associated with the buried beaches. While this may not disprove any relationship between the sites -- the same sea can have different effects at different points on the coast -- it limits any conclusions to little more than generalizations. Indeed, this is a major problem, for the amount of detailed stratigraphical work in the areas of the Postglacial transgression outside the Forth is very small. Even where the detail is good it is not always directly relevant in the present context. For example, the abundant information on the sub-arctic fossiliferous beds of the west of Scotland has been summarized by Sissons (1967a). These beds are immediately overlain by the sediments of the Postglacial sea and although the two deposits are not always separated by peat, they do not merge, implying a period of lower sea-level before the Postglacial rise, as was the case in the Forth. It may be suggested that the sub-arctic beds are, in part at least, equivalent to the Forth buried beaches, but beyond this it is not possible to be more specific.

Additional comparison might be attempted with the stratigraphy of certain sites in Northern Ireland but the evidence from Scotland illustrates one point more than adequately: nowhere outside the Forth have the sub-carse deposits been investigated in sufficient detail to allow anything more than very general conclusions regarding the situation preceding the Postglacial rise in sea-level. Undoubtedly there are similarities from area to area, as the above paragraphs have shown, but until areas such as the Solway and the Clyde have been studied more intensively the strength of the relationships must remain unknown.

Conclusion.

One of the more obvious conclusions that may be drawn from the present chapter is the great variability in the information available for the period during which the buried beaches were formed. Some is reasonably precise, but much may be used only with suitable qualification. This creates obvious problems when comparison is attempted, as above where the relatively abundant information from the Forth cannot be matched from other areas. Despite this, an examination of the available evidence indicates that the Forth valley is unlikely to be unique as far as the buried beaches are concerned and at the same time, the events that produced these features were not simply local in their mechanisms, but were related to much wider developments in the world as a whole.

CHAPTER X

CONCLUSION

The aims of the present research have been two-fold; firstly, to examine the stratigraphy and sub-carse morphology of the study area and secondly, to interpret the results obtained in terms of internal and external relationships in both time and place.

The morphology of the deposits lying beneath the carselands on the north side of the River Forth was deduced from an examination of the stratigraphy revealed by both shallow hand-boring and deeper commercial boring. Such methods inevitably produced, between boreholes, areas of "dead ground" through which the interpolation of stratigraphy and buried morphology was necessary and, because of the presence of the carse-clay, the overall form of the landscape, that is normally available to the surface geomorphologist for observation and measurement, was not even visible in the present study. However, such problems were minimized by working from a base of accurate quantitative information (as obtained by the combined use of the stratigraphical records collected with a Hiller borer and heights derived by levelling from Ordnance Survey bench-marks) and by the careful location of boreholes. Thus, despite the absence of directly observable features, it is submitted that the landscape revealed by the interpretation of the borehole evidence is essentially similar to that which would be exposed by the complete removal of the carse-clay.

The buried landscape includes areas of fine marine sediments forming raised beaches and coarser sands and gravels of varied origin. In the west, between Menteith and Blairdrummond, buried raised beaches predominate, forming a landscape similar to that of the carse in that it is subdued and composed of relatively fine marine sediments. However, the buried landscape has local variations in colour of sediments, composition and altitude that allow its division into three beaches, designated the High, Main and Low Buried Beaches. Associated with the beaches are the buried valleys of the Forth and Goodie Water along with the sand and gravel of the Menteith outwash and the alluvial fans of the burns that flow off the higher land backing the carse in this area.

In the west the buried beaches dominate the buried landscape, but from Blairdrummond as far as Stirling, outwash and fluvial deposits lie immediately beneath the carse to the exclusion of beach sediments. Originating mainly as outwash issuing from the Teith valley, the sand and gravel was later augmented and rearranged by fluvial activity and now forms the largest continuous morphological unit on the north side of the Forth.

Eastwards from Stirling, elements of the two western areas are present in the buried beaches between Abbey Craig and Menstrie, the alluvial fans of the Ochil Hills and the sand and gravel of the River Devon, but an addition to the buried landscape in this area is the buried gravel layer. Lying mainly in the vicinity of Kincardine-on-Forth, the latter is a marine feature formed prior to the buried beaches and consists of areas of planated rock and till as well as the gravel from which it takes its name.

Thus, over the study area as a whole the buried landscape possesses considerable variety, but a variety that is effectively masked by the carse-clay that makes up the present landscape.

The various elements summarized above indicate the presence north of the Forth of certain sub-carse features bearing a strong similarity to those already encountered south of the river. The buried beaches, for example, were first recognized by Sissons (1966) in the western part of the Carse of Stirling close to the Menteith Moraine and extending eastwards beneath the southern margins of the carse. The presence of similar features along the northern edge of the estuary in which the beaches were formed was not unexpected and this has now been confirmed. In addition, the distribution of the beaches located during the present study combined with that of beaches previously described, indicates the considerable extent of such features in the Forth valley as a whole. For example, the major system shown to be present in the angle of Abbey Craig and the Ochil Hills, east of Stirling, has indicated the existence of the High Buried Beach considerably farther east than previously located, while the patches of beach sediments, such as those at Hill of Drip and Cambus, together with the smaller remnants elsewhere, suggest the possibility of an even wider distribution of buried beaches at some time in the past.

While the buried beaches are the most prominent elements of the sub-carse morphology that can be compared with earlier work, the present study has also confirmed the existence of the buried gravel layer and its associated features on the northern side of the river and has shown that the buried valley of the Forth is part of a system of buried valleys that includes those beneath major rivers such as the Teith and the Devon and smaller streams such as the Goodie Water.

This supplements earlier evidence from the south side of the Forth, indicating buried valleys probably initiated during the period of low sea-level that preceded the formation of the buried beaches (Sissons, 1969). Other elements of the buried morphology to the north of the river, such as the extensive buried outwash of the Teith and the massive alluvial fans of the Ochils have no real equivalent to the south as far as size is concerned. This may be explained by the lack of major tributaries (except for the River Carron) joining the Forth from the south, the difference in relief to the north and south of the valley and the distribution of ice during the final stages of the last glaciation. The difference is largely one of scale in the case of the alluvial fans. The stratigraphy of those lying along the Ochil front shows that they were forming in Lateglacial times and have continued to grow with varying rapidity since then. Using evidence from the Grangemouth-Falkirk area, Sissons (1969) has inferred a limited amount of fluvial activity during the formation of the buried gravel layer and it is not unlikely that similar action was taking place at various points along the southern margin of the Forth valley where streams passed out from the hills. The alluvial fans that exist along the edge of the Campsie Fells, for example, might be compared to those of the Ochils and it seems probable that they would show similar lengthy development. Such similarities and the existence of more obviously comparable features on both sides of the river helps to establish the basic unity of the landscape that lies beneath the carse-clay of the Forth valley.

Although certain local conditions, such as the size of the estuary or its position with respect to the areas of the Zone III glaciation, might help to explain the considerable development of the buried beaches in the Forth, they are unlikely to be unique to that area, particularly when the influence of eustatic and isostatic changes are taken into consideration. It has been suggested (Chapter IX) that likely locations for similar features in other parts of Scotland would be in estuarine areas such as the Firths of Tay, Clyde and Solway in which deposits similar to those of the Forth carselands are known to exist. The sea-levels associated with the buried beaches probably produced features on the open coast also, although with the relatively short time spans during which the sea stood at a particular level, erosion would have been limited while the lack of material compared with the estuarine locations would have severely restricted the development of depositional forms. Thus, initial investigation in the estuarine areas noted above would appear likely to be more fruitful than work carried out on the open coast.

In the case of the buried gravel layer, however, the reverse may be true. The gravel layer is somewhat anomalous in that it represents a period of extensive marine erosion in an environment normally considered to be more conducive to deposition. It has been suggested (Chapter V) that the buried gravel layer came into being at a time when easterly winds were dominant in the Firth of Forth, producing an increased storminess that resulted in increased erosion. Such developments must have been paralleled on the North Sea coast of Scotland where increased exposure would have produced even greater erosion. Taking the altitude of the gravel layer in the Forth into consideration, it is probable that any equivalent of that layer along the east coast would be submerged off the present coastline. In such a position its investigation and measurement would not be without problems, but provided they could be overcome, the results might help to clarify the events that led to the formation of the buried gravel layer and its associated features.

Any equivalent of the buried gravel layer that might be submerged off the east coast of Scotland would be largely free from the effects of sub-aerial processes at the present time. If, as appears likely, this protection began shortly after the gravel layer came into being, the form of the feature would be relatively unaltered. The same applies to a considerable extent to the gravel layer of the Forth valley and to the buried beaches. Since they lie beneath the carse-clay, they have not been subject to erosion or weathering for the last 5000-6000 years. Prior to their submergence and burial some stream erosion did take place, particularly in the west, but on the whole they are remarkably well preserved. They are much better preserved, in fact, than the exposed raised beaches which have been altered over the years by geomorphological agencies and by the activities of man. As a result, the form of many of these exposed features must have changed significantly since they were produced, while their mechanical and chemical composition must have suffered under the effects of man's settlement and development of agriculture. In contrast the buried landscape of the Forth provides relatively extensive, well preserved segments of raised beaches. Because of the relatively simple and easily recognizable stratigraphical sequence with which they are associated, the problems often involved in the recognition of features as raised beaches appear less likely to apply. While not attempting to minimize the problems inherent in the study of buried beaches or their equivalents, it is suggested that investigation to establish their presence or absence in other parts of Scotland would be most beneficial, not only in terms of local geomorphology, but also in terms of more universal factors such as sea-level change or isostatic rebound.

The present study, for example, has confirmed the existence of a period of considerable sea-level oscillation during approximately 6000 years preceding the maximum of the Postglacial transgression. Accompanying, and partly explaining, these variations was a change in the level of the land produced by isostatic recovery following the decay of glacial ice. Examination and measurement of the buried beaches and their comparison with eustatic changes allowed rates of isostatic rebound to be calculated for the area. These fitted in with the generally accepted pattern of decreasing rapidity of uplift with time and with distance from the centre of maximum depression of the land, but the problems involved in reaching this conclusion amply illustrated the general inadequacy of the data employed in the estimation of eustatic change.

In addition, measurements along the buried beaches indicated shoreline tilting, considered to be produced by differential uplift. However, the results in this case were found to be at variance with the normal pattern of a beach shoreline with a single gradient throughout its length, for each shoreline was found to consist of a number of segments, each with a different gradient. It is possible that these conditions may be peculiar to the Forth valley or even to the buried beaches, or, as was indicated in Chapter IX, they may be explicable in terms of theories postulated by certain Scandanavian workers, but until the present information can be augmented, perhaps from similar features that may exist elsewhere in Scotland, the situation cannot be clarified.

At the present time, there is probably more information available on the raised beaches -- both buried and exposed -- of the Forth valley, than on those of any other area of comparable size in Scotland. The visible raised beaches have been studied there and elsewhere in Scotland for more than a century yet it is apparent that many problems still await solution. Perhaps the work on the buried beaches, which is only beginning, will initially add to these difficulties, but it is to be hoped that it will at least partially solve the earlier problem of limited information and reduce the misconceptions that arose as a result. The magnitude of the present information gap with respect to the buried beaches is apparent when it is considered that they, together with their associated features, represent a period of 5000-6000 years of geomorphological activity and 5000-6000 years of changes in the relative positions of land and sea as yet virtually untouched by geomorphologists. It is suggested that intensive studies such as those described for the Forth valley must be carried out in other parts of Scotland, probably initially in those areas that bear some stratigraphical and morphological similarity to the carselands of the Forth, if this gap is to be adequately filled.

APPENDIX A

BOREHOLE LOGS

Borehole	Height	Grid ref.
BH 1	13.3 m O.D.	NS 6602 9942

Depth	Description
0 - 191 cms	Carse.
191 + cms	Tough, grey/brown, silty sand with some shell fragments in top 2-3 cms.

Borehole	Height	Grid ref.
BH 2	13.6 m O.D.	NS 6602 9937

Depth	Description
0 - 244 cms	Carse.
244 + cms	Tough, grey/brown, silty sand. Quite large shell fragments in top 2-3 cms.

Borehole	Height	Grid ref.
BH 3	13.6 m O.D.	NS 6602 9932

Depth	Description
0 - 249 cms	Carse.
249 + cms	Tough, clayey sand.

Borehole	Height	Grid ref.
BH 4	13.5 m O.D.	NS 6602 9927

Depth	Description
0 - 252 cms	Carse.
252 + cms	Slightly purple/pink, clayey sand.

Borehole	Height	Grid ref.
BH 5	13.9 m O.D.	NS 6602 9947

Depth	Description
0 - 100 cms	Orange/red sand.
100 - 260 cms	Carse.
260 - 266 cms	Transition zone with shells.
266 + cms	Grey/brown, clayey sand with mica(?) and shell fragments.

Borehole	Height	Grid ref.
BH 6	14.2 m O.D.	NS 6602 9952

Depth	Description
0 - 100 cms	Reddish sand.
100 - 296 cms	Carse.
296 + cms	Grey/brown, clayey sand.

Borehole	Height	Grid ref.
BH 7	14.4 m O.D.	NS 6602 9957

Depth	Description
0 - 258 cms	Carse.
258 + cms	Pinky/grey, clayey sand with slight lamination.

Borehole	Height	Grid ref.
BH 8	14.6 m O.D.	NS 6602 9961

Depth	Description
0 - 160 cms	Carse/sand mixture.
160 - 180 cms	Waterlogged, brown sand.
180 - 271 cms	Carse-clay.
271 + cms	Pinkish/brownish/grey, clayey sand.

Borehole	Height	Grid ref.
BH 9	13.5 m O.D.	NS 6602 9922

Depth	Description
0 - 247 cms	Carse.
247 + cms	Grey/brown, clayey sand. Very tough.

BH 10		13.5 m O.D.	NS 6602 9917
0 - 253	cms	Carse.	
253 +	cms	Brownish/pink, clayey sand.	
BH 11		13.6 m O.D.	NS 6602 9912
0 - 268	cms	Carse.	
268 +	cms	Pinkish, clayey sand.	
BH 12		13.6 m O.D.	NS 6602 9907
0 - 277	cms	Carse.	
277 +	cms	Pinkish/purplish/brown, sandy clay.	
BH 13		13.6 m O.D.	NS 6602 9902
0 - 376	cms	Carse.	
376 +	cms	Grey, slightly brown, sandy clay. Very tough.	
BH 14		13.6 m O.D.	NS 6602 9903
0 - 311	cms	Carse.	
311 +	cms	Brownish/grey, sandy clay.	
BH 15		13.7 m O.D.	NS 6602 9904
0 - 334	cms	Carse.	
334 +	cms	Pinkish/grey, sandy clay.	
BH 16		13.6 m O.D.	NS 6602 9901
0 - 407	cms	Carse.	
407 +	cms	Pinkish/grey, sandy clay.	
BH 17		13.4 m O.D.	NS 6602 9896
0 - 440	cms	Carse.	
440 +	cms	Grey, sandy silt.	
BH 18		13.5 m O.D.	NS 6602 9895
0 - 609	cms	Carse.	
609 +	cms	Rock(?).	
BH 19		13.5 m O.D.	NS 6602 9894
0 - 613	cms	Carse.	
613 +	cms	Rock(?).	
BH 20		13.5 m O.D.	NS 6603 9894
0 - 612	cms	Carse.	
612 +	cms	Rock(?).	
BH 21		13.6 m O.D.	NS 6602 9888
0 - 639	cms	Carse.	
639 - 655	cms	Black, coarse, wet sand.	
655 +	cms	Tough, plastic, grey, sandy clay with pink streaks.	
BH 22		13.6 m O.D.	NS 6602 9890
0 - 610	cms	Carse.	
610 - 632	cms	Mixture of carse-clay and coarse, black sand.	
632 +	cms	Grey/brown, sandy clay with pinkish patches.	

BH 23		13.5 m O.D.	NS 6602 9892
0 - 628 cms	Carse.		
628 + cms	Rock(?).		
BH 24		12.8 m O.D.	NS 6602 9882
0 - 590 cms	Carse.		
590 - 601 cms	Transition zone - carse becomes more sandy eventually giving way to black sand.		
601 + cms	Very coarse sand or gravel.		
BH 25		11.7 m O.D.	NS 6602 9878
0 - 165 cms	Red/brown sand.		
165 - 182 cms	Dark brown sand.		
182 - 423 cms	Carse, - too tough for further penetration.		
BH 26		12.7 m O.D.	NS 6602 9872
0 - 591 cms	Carse.		
591 + cms	Gravel or rock.		
BH 27		13.3 m O.D.	NS 6602 9868
0 - 583 cms	Carse.		
583 + cms	Tough, grey, silty sand with numerous shell fragments (*Cardium*?).		
BH 28		13.4 m O.D.	NS 6602 9860
0 - 404 cms	Carse.		
404 - 409 cms	Carse/peat transition.		
409 - 437 cms	Peat, including flattened twigs and red coloured seeds with polished surfaces.		
437 + cms	Dark grey, silty sand.		
BH 29		13.0 m O.D.	NS 6602 9855
0 - 460 cms	Carse, - some peat fragments at base.		
460 + cms	Grey, silty sand.		
BH 30		13.4 m O.D.	NS 6602 9850
0 - 414 cms	Carse.		
414 - 441 cms	Peat, including red seeds.		
441 + cms	Grey, silty sand with some peat mixed in top 2-3 cms.		
BH 31		13.3 m O.D.	NS 6602 9845
0 - 434 cms	Carse - becoming more silty at c.400 cms.		
434 - 440 cms	Peat.		
440 + cms	Grey, silty sand with vegetation fragments down to c.5-6 cms in the deposit.		
BH 32		13.2 m O.D.	NS 6602 9841
0 - 417 cms	Carse.		
417 - 443 cms	Peat. Large piece of wood on top, also red seeds.		
443 + cms	Grey, silty sand.		
BH 33		13.4 m O.D.	NS 6602 9837
0 - 600 cms	Carse.		
600 + cms	Black, silty sand.		

BH 34	13.3 m O.D.	NS 6602 9832
0 - 406 cms	Carse.	
406 - 435 cms	Peat.	
435 - 440 cms	Transition zone.	
440 + cms	Grey, silty sand.	
BH 35	14.2 m O.D.	NS 6603 9828
0 - 43 cms	Moss Peat.	
43 - 640 cms	Carse.	
640 + cms	Grey, silty sand.	
BH 36	14.9 m O.D.	NS 6603 9822
0 - 129 cms	Moss Peat.	
129 - 629 cms	Carse - with some vegetable matter at c.145 cms.	
629 - 640 cms	Peat.	
640 + cms	Grey, silty sand.	
BH 37	14.7 m O.D.	NS 6603 9819
0 - 94 cms	Moss Peat.	
94 - 98 cms	Transition zone.	
98 - 552 cms	Carse.	
552 - 556 cms	Peat.	
556 - 570 cms	Transition zone.	
570 + cms	Grey, silty sand.	
BH 38	14.7 m O.D.	NS 6603 9815
0 - 126 cms	Moss peat, woody near base.	
126 - 135 cms	Transition zone.	
135 - 572 cms	Carse.	
572 - 606 cms	Peat.	
606 + cms	Grey, silty sand.	
BH 39	14.7 m O.D.	NS 6604 9811
0 - 112 cms	Moss Peat.	
112 - 116 cms	Transition zone.	
116 - 570 cms	Carse.	
570 - 590 cms	Peat.	
590 + cms	Grey, silty sand.	
BH 40	14.1 m O.D.	NS 6604 9808
0 - 46 cms	Moss Peat.	
46 - 48 cms	Transition zone.	
48 - 508 cms	Carse.	
508 - 529 cms	Peat, very woody at 522 cms.	
529 + cms	Grey, silty sand.	
BH 41	13.8 m O.D.	NS 6604 9803
0 - 15 cms	Moss Peat.	
15 - 470 cms	Carse. Shells at base.	
470 - 481 cms	Peat.	
481 + cms	Grey, silty sand.	

BH 42		13.8 m O.D.	NS 6604 9803
0 - 12 cms	Moss Peat.		
12 - 543 cms	Carse. Lowest 20-25 cms very rich in shell fragments - some up to 1.5 cms across.		
543 + cms	Slightly brown/grey, silty sand.		
BH 43		13.3 m O.D.	NS 6605 9794
0 - 410 cms	Carse.		
410 - 421 cms	Peat.		
421 - 427 cms	Transition zone.		
427 + cms	Grey, silty sand.		
BH 44		13.2 m O.D.	NS 6605 9789
0 - 420 cms	Carse.		
420 - 426 cms	Shell-bed. Large fragments. Carse quite sandy among shells.		
426 - 609 cms	Carse, still very shelly but dispersed between 521 and 565 cms.		
609 + cms	Grey sand. No sharp change and carse seems to merge with the lower deposit. Shells are in good condition. Mainly *Cardium* - both valves preserved together in several cases. Numerous small gastropods and possibly *Ostrea*.		
BH 45		13.2 m O.D.	NS 6605 9785
0 - 404 cms	Carse. Shells at base.		
404 + cms	Tough, grey, silty sand.		
BH 46		13.2 m O.D.	NS 6606 9780
0 - 472 cms	Carse.		
472 - 479 cms	Woody material.		
479 - 487 cms	Deposit similar to carse in colour but more silty. Seems to be a mixture of wood, carse and silty sand.		
487 + cms	Grey, silty sand.		
BH 47		13.2 m O.D.	NS 6608 9776
0 - 459 cms	Carse - some peat and wood fragments at c.50 cms.		
459 - 463 cms	Peat.		
463 + cms	Grey, silty sand.		
BH 48		13.2 m O.D.	NS 6610 9771
0 - 413 cms	Carse - some peat at c.30 cms.		
413 - 450 cms	Peat.		
450 - 453 cms	Transition zone.		
453 + cms	Grey, green, silty sand.		
BH 49		13.2 m O.D.	NS 6614 9769
0 - 433 cms	Carse.		
433 - 466 cms	Peat.		
466 + cms	Grey, silty sand.		
BH 50		13.1 m O.D.	NS 6616 9765
0 - 440 cms	Carse.		
440 - 471 cms	Peat, woody at top.		
471 + cms	Grey, silty sand.		

BH 51	13.1 m O.D.	NS 6620 9761
0 - 435 cms	Carse. Sandy with shells near base.	
435 - 468 cms	Peat.	
468 - 473 cms	Transition zone.	
473 + cms	Grey, silty sand.	
BH 52	13.2 m O.D.	NS 6622 9759
0 - 443 cms	Carse.	
443 - 470 cms	Peat.	
470 - 473 cms	Transition zone.	
473 + cms	Grey, silty sand.	
BH 53	13.1 m O.D.	NS 6626 9755
0 - 452 cms	Carse. Sandy with shell fragments near base.	
452 - 474 cms	Mixture of grey/brown, sandy material and peat, also including shells.	
474 + cms	Grey sand.	
BH 54	13.0 m O.D.	NS 6629 9750
0 - 415 cms	Carse.	
415 - 442 cms	Peat.	
442 + cms	Grey, silty sand.	
BH 55	13.2 m O.D.	NS 6626 9746
0 - 455 cms	Carse. Very sandy at junction with peat.	
455 - 471 cms	Peat.	
471 + cms	Grey, silty sand.	
BH 56	13.1 m O.D.	NS 6623 9741
0 - 453 cms	Carse. Sand and shells in bottom 5-6 cms.	
453 + cms	Peat. Impossible to penetrate beyond 490 cms.	
BH 57	13.0 m O.D.	NS 6621 9739
0 - 540 cms	Carse.	
540 - 550 cms	Possibly peat, exact thickness not known.	
550 + cms	Grey/green, silty sand.	
BH 58	12.8 m O.D.	NS 6619 9734
0 - 542 cms	Carse.	
542 + cms	Dark grey, silty clay.	
BH 59	11.7 m O.D.	NS 6619 9730
0 - 359 cms	Carse.	
359 - 402 cms	Peat, with tree at base.	
402 + cms	Grey, silty clay.	
BH 60	12.2 m O.D.	NS 6619 9725
0 - 409 cms	Carse.	
409 - 416 cms	Transition zone.	
416 - 440 cms	Peat.	
440 + cms	Grey, silty clay.	

BH 61	12.1 m O.D.	NS 6619 9720
0 - 392 cms	Carse.	
392 - 396 cms	Transition zone.	
396 - 422 cms	Peat.	
422 + cms	Grey, silty clay with numerous vegetable fragments.	
BH 62	12.2 m O.D.	NS 6619 9715
0 - 585+ cms	Carse, becoming increasingly sandy downwards. Samples at 511, 523, 573, and 585 cms all showed this sandy version of the carse. No sharp transition.	
BH 63	12.7 m O.D.	NS 6601 9685
0 - 710+ cms	Carse, base not reached. Sample at 710 cms was dark blue/grey, smelly carse which was difficult to penetrate.	
BH 64	12.2 m O.D.	NS 6600 9640
0 - 470+ cms	Carse, base not reached. Sample at 470 cms was tough, dark blue/grey, smelly clay.	
BH 65	11.6 m O.D.	NS 6660 9619
0 - 500+ cms	Carse, becoming sandier downwards and giving way at c.336 cms to layers of sand and clay. Similar sample examined at 500 cms.	
BH 66	10.5 m O.D.	NS 6660 9600
0 - 150 cms	Red, clayey sand.	
150 + cms	Carse, very tough and slightly brown. Similar sample at 400 cms.	
BH 67	13.7 m O.D.	NS 6792 9839
0 - 73 cms	Carse, top 6-9 cms a mixture of carse-clay and material washed off slope. Becoming sandier downwards.	
73 + cms	Red/maroon sand and gravel.	
BH 68	13.1 m O.D.	NS 6793 9831
0 - 260 cms	Carse. Sandy red near top (O.R.S.?).	
260 + cms	Rock or gravel(?).	
BH 69	13.7 m O.D.	NS 6796 9832
0 - 278 cms	Carse. Sandy red at top, very dark blue towards base.	
278 + cms	Gravel(?).	
BH 70	13.8 m O.D.	NS 6797 9832
0 - 215 cms	Carse. Certain amount of brown, soft, woody deposit immediately below surface. Carse very sandy and brownish/grey in colour.	
215 + cms	Rock or gravel(?).	
BH 71	13.8 m O.D.	NS 6798 9834
0 - 115 cms	Carse.	
115 + cms	Gravel(?).	

BH 72 — 13.1 m O.D. — NS 6792 9830

0 - 428 cms	Carse. Carse very sandy near base with considerable proportion of shell fragments in grey, sandy matrix.
428 + cms	Rock or gravel(?).

BH 73 — 12.9 m O.D. — NS 6789 9830

0 - 449 cms	Carse.
449 + cms	Grey sand. Boring stopped by toughness of the sand at 458 cms.

BH 74 — 12.8 m O.D. — NS 6785 9829

0 - 472+ cms	Carse. Becomes quite sandy at c.467 cms but no sharp change.

BH 75 — 13.0 m O.D. — NS 6777 9826

0 - 485+ cms	Carse. Very tough.

BH 76 — 12.9 m O.D. — NS 6804 9829

0 - 274 cms	Carse with bands of sand and shells.
274 - 357 cms	Red sand and stones.
357 + cms	Yellow sand with clay.

BH 77 — 13.2 m O.D. — NS 6804 9829

0 - 293 cms	Carse, very stoney on top.
293 + cms	Red/maroon gravel (O.R.S.?).

BH 78 — 14.1 m O.D. — NS 6804 9830

0 - 20 cms	Red/brown sandy clay.
20 + cms	Rock(?).

BH 79 — 13.6 m O.D. — NS 6804 9830

0 - 244 cms	Carse.
244 + cms	Gravel(?).

BH 80 — 12.7 m O.D. — NS 6804 9827

0 - 349 cms	Carse. Quite sandy at top.
349 - 354 cms	Sand and vegetable matter.
354 + cms	Greyish/yellow, clayey sand.

BH 81 — 12.7 m O.D. — NS 6803 9824

0 - 378 cms	Carse.
378 + cms	Tough, grey sand.

BH 82 — 12.6 m O.D. — NS 6800 9820

0 - 440 cms	Carse.
440 + cms	Tough, grey sand.

BH 83 — 12.6 m O.D. — NS 6798 9817

0 - 486 cms	Carse.
486 + cms	Grey sand.

BH 84 — 12.3 m O.D. — NS 6792 9812

0 - 456 cms	Carse.
456 + cms	Tough, grey sand.

BH 85		12.3 m O.D.	NS 6792 9806
0 - 487 cms	Carse.		
487 + cms	Tough, grey sand.		
BH 86		12.1 m O.D.	NS 6791 9799
0 - 433 cms	Carse.		
433 + cms	Tough, grey sand.		
BH 87		12.2 m O.D.	NS 6790 9790
0 - 486 cms	Carse. Very shelly near base, fragments suggest *Mytilus* and *Ostrea*.		
486 + cms	Tough, grey sand.		
BH 88		10.7 m O.D.	NS 6793 9785
0 - 316 cms	Carse. Abundant shells in bottom 50 cms.		
316 + cms	Tough, grey, silty sand.		
BH 89		12.0 m O.D.	NS 6794 9780
0 - 462 cms	Carse. Very tough.		
462 + cms	Tough, grey/brown sand, slightly silty.		
BH 90		9.6 m O.D.	NS 6796 9777
0 - 280+ cms	Carse. Too tough to penetrate beyond 280 cms.		
BH 91		11.5 m O.D.	NS 6798 9775
0 - 415+ cms	Tough carse.		
BH 92		12.7 m O.D.	NS 6798 9770
0 - 600+ cms	Carse, exceedingly tough.		
BH 93		12.9 m O.D.	NS 6799 9766
0 - 750 cms	Carse. Becomes increasingly tough downwards.		
750 + cms	Grey, sandy deposit.		
BH 94		12.3 m O.D.	
0 - 722 cms	Carse. Shell fragments at base.		
722 + cms	Tough, grey sand.		
BH 95		12.8 m O.D.	NS 6802 9748
0 - 816 cms	Carse. Very tough downwards.		
816 + cms	Gravel or very coarse sand.		
BH 96		12.8 m O.D.	NS 6803 9733
0 - 815 cms	Carse.		
815 + cms	Gravel(?).		
BH 97		12.6 m O.D.	NS 6804 9719
0 - 698 cms	Carse.		
698 + cms	Tough, grey sand.		
BH 98		9.3 m O.D.	NS 6602 9712
0 - 190+ cms	Carse. Sandy at top.		

BH 99		13.3 m O.D.	NS 6968 9810
0 - 132	cms	Carse. Top 50 cms mainly red sand.	
132 +	cms	Red/brown sand with maroon fragments.	
BH 100		13.7 m O.D.	NS 6968 9809
0 - 40	cms	Red sand.	
40 +	cms	Rock or rock fragments.	
BH 101		13.1 m O.D.	NS 6968 9808
0 - 60	cms	Red sand.	
60 - 208	cms	Carse. Shells at base.	
208 +	cms	Gravel or rock fragments.	
BH 102		13.2 m O.D.	NS 6968 9806
0 - 322	cms	Carse.	
322 - 396	cms	Peat.	
396 +	cms	Light grey, silty clay.	
BH 103		13.1 m O.D.	NS 6968 9807
0 - 305	cms	Carse.	
305 - 372	cms	Peat.	
372 +	cms	Grey/green, silty clay.	
BH 104		12.5 m O.D.	NS 6969 9801
0 - 331	cms	Carse.	
331 - 403	cms	Peat.	
403 +	cms	Grey, silty sand.	
BH 105		13.0 m O.D.	NS 6963 9791
0 - 385	cms	Carse.	
385 - 415	cms	Peat, woody at top.	
415 - 462	cms	Mixture of peat and silty clay.	
462 +	cms	Grey, silty sand.	
BH 106		12.9 m O.D.	NS 6964 9795
0 - 359	cms	Carse.	
359 - 392	cms	Peat, woody near top.	
392 - 428	cms	Grey/green, silty clay with vegetable matter.	
428 +	cms	Grey, silty sand.	
BH 107		13.1 m O.D.	NS 6965 9783
0 - 420	cms	Carse.	
420 - 455	cms	Thin layer of peat resting on grey/green, silty clay with peat fragments.	
455 +	cms	Grey, silty sand.	
BH 108		13.0 m O.D.	NS 6965 9783
0 - 466	cms	Carse.	
466 +	cms	Grey, silty sand.	
BH 109		13.1 m O.D.	NS 6968 9774
0 - 500+	cms	Carse. Very tough.	

BH 110	13.0 m O.D.	NS 6968 9769
0 - 514+ cms	Carse. Very tough.	
BH 111	13.0 m O.D.	NS 6968 9765
0 - 400+ cms	Carse. Very tough.	
BH 112	12.9 m O.D.	NS 6967 9747
0 - c540 cms	Carse. Very tough with layers of sand.	
540 + cms	Tough, blue/black sand.	
BH 113	8.3 m O.D.	NS 6967 9727
0 - 259 cms	Carse. Slightly sandy at top.	
259 + cms	Carse-like deposit, but brownish and more sandy.	
BH 114	11.9 m O.D.	NS 6977 9717
0 - 120+ cms	Carse. Further penetration impossible.	
BH 115	11.9 m O.D.	NS 6975 9714
0 - 542+ cms	Carse. Becomes very blue downwards with included layers of sand and shells.	
BH 116	12.6 m O.D.	NS 6974 9705
0 - 405+ cms	Tough carse. Dark blue, smelly clay with occasional layers of sand in places.	
BH 117	11.8 m O.D.	NS 6974 9693
0 - 465+ cms	Tough carse. Sandy with depth.	
BH 118	11.3 m O.D.	NS 6974 9685
0 - 321+ cms	Carse. Blue clay, somewhat sandy with depth.	
BH 119	10.8 m O.D.	NS 6975 9674
0 - 174+ cms	Tough carse. Very red near the top, probably due to mixture of sand from the Forth.	
BH 120	15.2 m O.D.	NN 6531 0015
0 - 164 cms	Clay/sand/peat mixture in top 60 cms but mainly peat, with woody fragments beyond this.	
164 - 170 cms	Transition, grey, peat/clay zone.	
170 + cms	Grey, shelly sand.	
BH 121	15.8 m O.D.	NN 6531 0015
0 - 100 cms	Brown sand with stones.	
100 - 202 cms	Peat, containing considerable clay below c.170 cms.	
202 + cms	Grey sand.	
BH 122	16.5 m O.D.	NN 6531 0015
0 - 100 cms	Brown sand.	
100 - 115 cms	Peaty sand.	
115 + cms	Rock fragments.	
BH 123	15.1 m O.D.	NN 6531 0015
0 - 40 cms	Sand/clay/peat mixture.	
40 - 168 cms	Peat with wood.	
168 + cms	Grey sand with slight pink tinge.	

BH 124		15.1 m O.D.	NN 6530 0012
0 - 40	cms	Sandy clay becoming peaty.	
40 - 172	cms	Peat.	
172 +	cms	Rock or big gravel.	
BH 125		14.8 m O.D.	NN 6529 0010
0 - 125	cms	Surface peat.	
125 +	cms	Grey sand and gravel. Some pink coloration.	
BH 126		14.7 m O.D.	NN 6528 0008
0 - 131	cms	Peat with peat/clay mixture in top 0.5 m.	
131 +	cms	Coarse, grey, sandy gravel.	
BH 127		14.3 m O.D.	NN 6527 0004
0 - 134	cms	Surface peat.	
134 - 139	cms	Peat/clay transition.	
139 +	cms	Grey sand with some pink coloration.	
BH 128		13.6 m O.D.	NN 6525 0001
0 - 30	cms	Surface peat with sand/clay mixture.	
30 - 87	cms	Carse-clay with reeds and root fragments in top 20 cms.	
87 - 122	cms	Peat.	
122 +	cms	Grey/brown, silty sand.	
BH 129		13.9 m O.D.	NN 6526 0000
0 - 34	cms	Surface peat.	
34 - ?	cms	Carse-clay with roots and other vegetable matter.	
? - 137	cms	Peat.	
137 +	cms	Gravel(?).	
BH 130		14.1 m O.D.	NN 6526 0003
0 - 26	cms	Surface peat.	
26 - 27	cms	Clay/peat mixture.	
27 - 139	cms	Peat.	
139 - 144	cms	Grey, peaty, clay transition mixture.	
144 +	cms	Pinkish sand.	
BH 131		13.8 m O.D.	NS 6519 9994
0 - 183	cms	Carse.	
183 - 229	cms	Peat.	
229 - 233	cms	Clay/peat transition.	
233 +	cms	Pinkish sand with grey streaks.	
BH 132		13.8 m O.D.	NS 6514 9988
0 - 177	cms	Carse.	
177 - 202	cms	Peat, woody at base.	
202 +	cms	Pinkish/grey sand. Grey at top, becoming pink downwards.	
BH 133		13.7 m O.D.	NS 6511 9982
0 - 196	cms	Carse.	
196 - 202	cms	Peat fragments.	
202 +	cms	Sandy version of carse becoming slightly pink or grey/brown downwards.	

BH 134	12.9 m O.D.	NS 6492 9958
0 - 474 cms	Wet, red and brown sand.	
474 + cms	Blue/black sand.	
BH 135	13.4 m O.D.	NS 6493 9962
0 - 450+ cms	Carse. Blue/black sand in places.	
BH 136	13.7 m O.D.	NS 6496 9965
0 - 193 cms	Carse.	
193 + cms	Pink/brown, silty sand.	
BH 137	13.6 m O.D.	NS 6495 9964
0 - 237 cms	Carse.	
237 + cms	Grey, silty sand with pink and brown streaks.	
BH 138	13.6 m O.D.	NS 6495 9963
0 - 304 cms	Carse. Very blue towards base.	
304 + cms	Grey/pink, silty sand.	
BH 139	13.4 m O.D.	NS 6494 9963
0 - 358 cms	Carse, toughening downwards.	
358 + cms	Blue/black, silty sand.	
BH 140	12.6 m O.D.	NS 6491 9955
0 - 69 cms	Carse.	
69 - 80 cms	Peat.	
80 - 90 cms	Grey sand.	
90 + cms	Rock or gravel(?).	
BH 141	12.2 m O.D.	NS 6492 9956
0 - 70 cms	Sandy carse.	
70 + cms	Rock(?).	
BH 142	12.8 m O.D.	NS 6491 9955
0 - 501 cms	Carse.	
501 + cms	Blue/black, sandy gravel.	
BH 143	13.1 m O.D.	NS 6491 9952
0 - 557 cms	Carse.	
557 + cms	Dark blue/black, coarse sand with some red (O.R.S.?) fragments.	
BH 144	13.3 m O.D.	NS 6489 9949
0 - 585 cms	Carse, becoming very black downwards.	
585 + cms	Coarse, black, sandy gravel.	
BH 145	13.2 m O.D.	NS 6489 9946
0 - 561 cms	Carse, with some sandy streaks near base.	
561 + cms	Gravel(?).	
BH 146	13.3 m O.D.	NS 6489 9945
0 - 308 cms	Carse.	
308 - 368 cms	Peat.	
368 + cms	Grey, silty sand, slightly green in places.	

BH 147	13.5 m O.D.	NS 6489 9942
0 - 286 cms	Carse.	
286 - 356 cms	Peat with large, woody fragments near base.	
356 + cms	Grey, silty sand.	
BH 148	13.3 m O.D.	NS 6489 9934
0 - 270 cms	Carse.	
270 - 352 cms	Peat.	
352 + cms	Grey, silty sand.	
BH 149	13.5 m O.D.	NS 6489 9922
0 - 348 cms	Carse.	
348 - 425 cms	Peat.	
425 + cms	Grey, silty sand.	
BH 150	13.4 m O.D.	NS 6491 9915
0 - 284 cms	Carse.	
284 - 388 cms	Peat. Quite woody near base.	
388 + cms	Grey, silty clay becoming more sandy with depth.	
BH 151	13.7 m O.D.	NS 6491 9907
0 - 259 cms	Carse.	
259 - 366 cms	Peat, woody near base.	
366 + cms	Grey, silty sand.	
BH 152	13.7 m O.D.	NS 6492 9891
0 - 244 cms	Carse.	
244 - 365 cms	Peat.	
365 + cms	Grey, silty clay.	
BH 153	14.9 m O.D.	NS 6491 9878
0 - 123 cms	Moss peat.	
123 - 377 cms	Carse.	
377 - 491 cms	Peat.	
491 + cms	Grey, silty sand.	
BH 154	15.2 m O.D.	NS 6491 9868
0 - 111 cms	Moss peat.	
111 - 394 cms	Carse.	
394 - 512 cms	Peat.	
512 + cms	Grey, silty sand.	
BH 155	16.3 m O.D.	NS 6491 9864
0 - 233 cms	Moss peat, wood at base.	
233 - 547 cms	Carse.	
547 - 649 cms	Peat.	
649 + cms	Grey, silty sand.	
BH 156	18.2 m O.D.	NS 6491 9848
0 - 428 cms	Moss peat.	
428 - 778 cms	Carse.	
778 - 860 cms	Peat, very dark with fragments of reeds.	
860 + cms	Grey, silty sand.	

BH 157	17.9 m O.D.	NS 6491 9829
0 - 388 cms	Moss peat, woody near base.	
388 - 743 cms	Carse.	
743 - 819 cms	Peat.	
819 + cms	Grey, silty sand.	
BH 158	17.8 m O.D.	NS 6502 9818
0 - 378 cms	Moss peat, slightly woody at base.	
378 - 782 cms	Carse.	
782 - 850 cms	Peat.	
850 + cms	Grey, silty clay with sand.	
BH 159	17.8 m O.D.	NS 6507 9801
0 - 378 cms	Moss peat.	
378 - 809 cms	Carse.	
809 - 840 cms	Peat, piece of tree near top.	
840 + cms	Grey, slightly green, silty sand.	
BH 160	16.8 m O.D.	NS 6509 9795
0 - 295 cms	Moss peat.	
295 - 788 cms	Carse.	
788 + cms	Grey, silty sand.	
BH 161	14.5 m O.D.	NS 6512 9793
0 - 49 cms	Moss peat.	
49 - 524 cms	Carse, shell fragments in lowest 6 cms.	
524 + cms	Grey, silty sand.	
BH 162	14.1 m O.D.	NS 6505 9779
0 - 442 cms	Carse, slightly peaty in top 5-10 cms.	
442 - 463 cms	Peat.	
463 + cms	Grey, silty sand.	
BH 163	13.4 m O.D.	NS 6505 9767
0 - 492 cms	Carse.	
492 - 547 cms	Peat, very woody near base.	
547 - 563 cms	Peat/clay/silty sand mixture.	
563 + cms	Grey, silty sand.	
BH 164	13.6 m O.D.	NS 6511 9762
0 - 561 cms	Carse.	
561 - 615 cms	Peat, very tough and woody.	
615 - 627 cms	Grey clay.	
627 + cms	Grey, silty sand with a considerable proportion of clay.	
BH 165	13.6 m O.D.	NS 6508 9751
0 - 544 cms	Carse.	
544 - 595 cms	Peat, quite woody at top.	
595 + cms	Grey, silty sand with clay in top 10 cms.	
BH 166	13.5 m O.D.	NS 6509 9743
0 - 690 cms	Carse. Shell bed between 663-675 cms.	
690 + cms	Dark grey, tough, shelly sand.	

BH 167		13.6 m O.D.	NS 6508 9746
0 - 751 cms	Carse.		
751 + cms	Grey, silty sand.		
BH 168		13.6 m O.D.	NS 6508 9748
0 - 698 cms	Carse.		
698 + cms	Grey, silty sand.		
BH 169		13.5 m O.D.	NS 6508 9749
0 - 557 cms	Carse.		
557 - 604 cms	Peat, mixed with clay or fine sand beyond 568 cms.		
604 + cms	Grey, silty clay.		
BH 170		13.3 m O.D.	NS 6503 9732
0 - 543 cms	Carse.		
543 + cms	Peat(?).		
BH 171		13.2 m O.D.	NS 6504 9729
0 - 528 cms	Carse. Very sandy in places especially near the base.		
528 - 553 cms	Very tough peat.		
553 + cms	Grey clay.		
BH 172		13.1 m O.D.	NS 6505 9725
0 - 539 cms	Carse. Very sandy near base.		
539 - 563 cms	Peat.		
563 + cms	Grey clay. Vegetable matter in top 3-5 cms.		
BH 173		13.1 m O.D.	NS 6505 9721
0 - 532 cms	Carse. Quite sandy near base.		
532 - 548 cms	Peat.		
548 + cms	Grey clay.		
BH 174		12.9 m O.D.	NS 6508 9712
0 - 500+ cms	Tough carse.		
BH 175		12.9 m O.D.	NS 6508 9716
0 - 535 cms	Carse.		
535 - 547 cms	Peat.		
547 + cms	Grey clay.		
BH 176		13.0 m O.D.	NS 6508 9717
0 - 539 cms	Carse. Quite sandy immediately above peat.		
539 - 549 cms	Peat.		
549 + cms	Grey clay with clay/peat mixture in top 2-3 cms.		
BH 177		12.8 m O.D.	NS 6511 9707
0 - 560+ cms	Tough carse.		
BH 178		12.6 m O.D.	NS 6514 9696
0 - 432+ cms	Carse. Alternating tough and soft layers.		
BH 179		8.6 m O.D.	NS 6514 9686
0 - 278+ cms	Carse, mixed in top metre with brown sand.		

BH 180	8.3 m O.D.	NS 6537 9694
0 - 200+ cms	Carse with brown sand on top.	
BH 181	14.9 m O.D.	NS 7149 9853
0 - 45 cms	Brown sand.	
45 + cms	Pink and brown, weathered rock.	
BH 182	14.8 m O.D.	NS 7148 9852
0 - 100+ cms	Pink sand mixed with clay in top 20 cms.	
BH 183	14.6 m O.D.	NS 7147 9849
0 - 100+ cms	Pink sand mixed with clay.	
BH 184	13.8 m O.D.	NS 7146 9847
0 - 112 cms	Carse.	
112 + cms	Pinkish sand and gravel.	
BH 185	14.4 m O.D.	NS 7148 9849
0 - 45 cms	Carse.	
45 + cms	Reddish sand and gravel.	
BH 186	13.4 m O.D.	NS 7146 9846
0 - 165 cms	Carse.	
165 - 288 cms	Peat, dark at top becoming lighter and tougher downwards.	
288 + cms	Light grey, silty sand. Very micaceous.	
BH 187	13.5 m O.D.	NS 7145 9845
0 - 215 cms	Carse.	
215 - 248 cms	Peat.	
248 - 264 cms	Peat/clay mixture.	
264 + cms	Grey and pink sand and gravel.	
BH 188	13.2 m O.D.	NS 7144 9842
0 - 135 cms	Carse.	
135 - 151 cms	Carse with layers of peat 3-5 cms thick.	
151 - 291 cms	Woody peat.	
291 + cms	Light grey/green, silty sand.	
BH 189	12.5 m O.D.	NS 7142 9839
0 - c100 cms	Carse.	
100 - 232 cms	Peat.	
232 + cms	Light grey/green, silty sand.	
BH 190	12.8 m O.D.	NS 7139 9834
0 - 126 cms	Carse.	
126 - 149 cms	Carse with thin layers of peat.	
149 - 269 cms	Peat, woody at top.	
269 + cms	Light grey/green, silty sand.	
BH 191	12.7 m O.D.	NS 7137 9827
0 - 135 cms	Carse.	
135 - 284 cms	Peat, very woody in places.	
284 + cms	Light grey/green, silty sand.	

BH 192	12.6 m O.D.	NS 7132 9819
0 - 203 cms	Carse.	
203 - 320 cms	Peat.	
320 + cms	Light grey/green, silty sand, with clay in top 20 cms.	

BH 193	12.6 m O.D.	NS 7129 9811
0 - 227 cms	Carse.	
227 - 315 cms	Peat, woody at top.	
315 + cms	Light grey/green, silty sand. Clay at top.	

BH 194	12.3 m O.D.	NS 7128 9802
0 - 291 cms	Carse.	
291 - 356 cms	Peat.	
356 + cms	Grey/green, silty sand. Top 10-15 cms contain high proportion of clay.	

BH 195	12.6 m O.D.	NS 7121 9792
0 - 346 cms	Carse.	
346 - 407 cms	Peat.	
407 + cms	Light grey, silty clay, sandy with depth.	

BH 196	12.5 m O.D.	NS 7122 9797
0 - 337 cms	Carse.	
337 - 389 cms	Peat.	
389 + cms	Light grey (green) silty clay.	

BH 197	12.6 m O.D.	NS 7118 9786
0 - 368 cms	Carse.	
368 - 397 cms	Peat.	
397 + cms	Light grey, silty clay becoming coarser downwards.	

BH 198	12.4 m O.D.	NS 7113 9778
0 - 358 cms	Carse.	
358 - 391 cms	Peat.	
391 + cms	Light grey, silty clay.	

BH 199	12.5 m O.D.	NS 7109 9769
0 - 387 cms	Carse.	
387 - 416 cms	Peat. Tough and woody at top.	
416 + cms	Greenish/grey, silty clay, tending to coarsen downwards.	

BH 200	12.4 m O.D.	NS 7105 9762
0 - 403 cms	Carse.	
403 - 437 cms	Grey, slightly green, silty sand.	
437 + cms	Pinkish/grey sand.	

BH 201	12.5 m O.D.	NS 7108 9765
0 - 392 cms	Carse.	
392 - 404 cms	Peat. Tough and woody at top.	
404 - 467 cms	Light grey, silty sand.	
467 + cms	Grey/brown, silty sand.	

BH 202	12.5 m O.D.	NS 7105 9756
0 - 460 cms	Carse.	
460 + cms	Pinkish/grey, silty sand.	
BH 203	12.0 m O.D.	NS 7105 9752
0 - 448 cms	Tough carse.	
448 + cms	Dark grey, silty sand.	
BH 204	12.1 m O.D.	NS 7107 9748
0 - 489 cms	Carse.	
489 + cms	Dark grey, silty sand.	
BH 205	12.1 m O.D.	NS 7109 9742
0 - 543 cms	Carse.	
543 + cms	Greyish/brown, silty sand.	
BH 206	12.0 m O.D.	NS 7111 9736
0 - 624 cms	Carse.	
624 + cms	Tough, grey, silty sand.	
BH 207	12.6 m O.D.	NS 7113 9728
0 - 712 cms	Carse. Layers of sand beneath 500 cms.	
712 + cms	Tough, grey sand.	
BH 208	12.6 m O.D.	NS 7115 9722
0 - 438 cms	Carse.	
438 + cms	Dark grey, silty sand.	
BH 209	12.6 m O.D.	NS 7116 9716
0 - 417 cms	Carse.	
417 + cms	Dark grey, sandy silt.	
BH 210	12.5 m O.D.	NS 7119 9709
0 - 444 cms	Carse.	
444 + cms	Dark grey/blue, silty sand.	
BH 211	12.3 m O.D.	NS 7121 9702
0 - 506 cms	Carse.	
506 + cms	Dark grey, silty sand.	
BH 212	12.6 m O.D.	NS 7115 9725
0 - 500+ cms	Tough, sandy carse.	
BH 213	Not Levelled	NS 7125 9691
0 - 570+ cms	Carse. Becomes tougher downwards. Merges with grey sand between 560 and 570 cms.	
BH 214	Not Levelled	NS 7128 9682
0 - 450+ cms	Carse. Dark blue/black with thin bands of sand.	
BH 215	Not Levelled	NS 7132 9667
0 - 647+ cms	Carse. Tough, blue/black clay with bands of sand.	

BH 216		Not Levelled	NS 7138 9651
0 - 477+ cms	Carse. Dark blue and sandy. Some shell fragments.		
BH 217		Not Levelled	NS 7141 9641
0 - 550+ cms	Carse. Tough, dark blue, sandy sediments.		
BH 218		10.8 m O.D.	NS 7155 9641
0 - 505+ cms	Carse. Shell-bed -- 439-445 cms. Easily recognisable as *Cardium*. Both values complete in some cases. Quite small (2 cms). Bands of sand begin to appear below the shell-bed and deposit toughens.		
BH 219		10.5 m O.D.	NS 7164 9590
0 - 700+ cms	Carse. Coarser with depth.		
BH 220		10.5 m O.D.	NS 7154 9530
0 - 550+ cms	Carse. Sandier with depth.		
BH 221		10.6 m O.D.	NS 7158 9641
0 - 490+ cms	Carse. Dark blue, tough carse, with occasional shells.		
BH 222		12.9 m O.D.	NS 7188 9841
0 - 235 cms	Carse. Mixed with peat near base.		
235 - 277 cms	Peat.		
277 + cms	Grey, silty sand.		
BH 223		12.4 m O.D.	NS 7188 9783
0 - 379 cms	Carse.		
379 + cms	Grey sand.		
BH 224		11.9 m O.D.	NS 7180 9716
0 - 635 cms	Carse.		
635 + cms	Coarse sand and gravel.		
BH 225		11.2 m O.D.	NS 7172 9650
0 - 561 cms	Carse.		
561 + cms	Coarse sand.		
BH 226		13.4 m O.D.	NS 7318 9822
0 - 92 cms	Carse.		
92 + cms	Gravel.		
BH 227		14.1 m O.D.	NS 7284 9843
0 - 150 cms	Carse.		
150 + cms	Gravel.		
BH 228		12.3 m O.D.	NS 7327 9821
0 - 110 cms	Carse.		
110 + cms	Gravel.		
BH 229		12.3 m O.D.	NS 7337 9816
0 - 105 cms	Carse.		
105 + cms	Gravel.		

BH 230		12.0 m O.D.	NS 7386 9691
0 - 174 cms	Moss peat.		
174 - 550 cms	Carse.		
550 + cms	Gravel.		
BH 231		10.8 m O.D.	NS 7167 9643
0 - 586+ cms	Carse. Very tough near base.		
BH 232		10.3 m O.D.	NS 7169 9647
0 - 547+ cms	Carse. Boring stopped by blue/black clay alternating with very thin bands of sand.		
BH 233		10.6 m O.D.	NS 7171 9651
0 - 532+ cms	Tough carse.		
BH 234		11.2 m O.D.	NS 7173 9657
0 - 356+ cms	Tough, blue/black carse.		
BH 235		10.9 m O.D.	NS 7175 9641
0 - 479+ cms	Tough, blue/black carse.		
BH 236		9.5 m O.D.	NS 7175 9639
0 - 295+ cms	Tough, blue/black carse.		
BH 237		11.5 m O.D.	NS 7179 9659
0 - 600 cms	Carse. Thin, sandy bands with shell fragments near base.		
600 + cms	Clay with sand and small gravel.		
BH 238		11.4 m O.D.	NS 7177 9661
0 - 575+ cms	Tough, blue/black carse.		
BH 239		11.5 m O.D.	NS 7187 9658
0 - 614 cms	Carse, with thin bands of sand and shell fragments in bottom 10-15 cms.		
614 + cms	Coarse, brown/grey sand.		
BH 240		11.4 m O.D.	NS 7195 9655
0 - 534+ cms	Tough, black carse.		
BH 241		11.7 m O.D.	NS 7199 9668
0 - 531+ cms	Tough, blue/black carse.		
BH 242		11.9 m O.D.	NS 7207 9664
0 - 405+ cms	Carse. Increasingly tough and sandy with depth.		
BH 243		11.8 m O.D.	NS 7213 9682
0 - 343+ cms	Tough carse.		
BH 244		11.8 m O.D.	NS 7198 9688
0 - 116 cms	Carse.		
116 - 126 cms	Hard, black, wood fragments.		
126 - 450 cms	Carse. Becoming sandier at c.440 cms.		
450 + cms	Coarse, brown/grey sand.		

BH 245	11.3 m O.D.	NS 7415 9737
0 - 179 cms	Carse.	
179 + cms	Red sand and gravel probably associated with Nyadd rock.	

BH 246	11.1 m O.D.	NS 7421 9735
0 - 191 cms	Very tough carse.	
191 - 205 cms	Sand and small gravel.	
205 - 209 cms	Grey clay with some vegetable fragments.	
209 + cms	Coarse sand and gravel.	

BH 247	10.6 m O.D.	NS 7433 9732
0 - 144 cms	Carse.	
144 - 180 cms	Coarse sand and small gravel.	
180 - 200 cms	Grey clay with vegetable fragments.	
200 + cms	Gravel, quartz rich and quite angular.	

BH 248	10.9 m O.D.	NS 7432 9729
0 - 184 cms	Carse.	
184 + cms	Coarse sand and gravel.	

BH 249	11.9 m O.D.	NS 7412 9734
0 - 79 cms	Carse - mixed with pink sand from rock especially in bottom 10-20 cms.	
79 + cms	Rock.	

BH 250	11.5 m O.D.	NS 7413 9736
0 - 126 cms	Carse.	
126 - 138 cms	Carse and bands of red, micaceous sand.	
138 + cms	Rock - very thin band of coarse sand on top.	

BH 251	10.5 m O.D.	NS 7409 9728
0 - 220 cms	Carse.	
220 + cms	Rock.	

BH 252	11.2 m O.D.	NS 7407 9724
0 - 286 cms	Carse.	
286 - 294 cms	Grey, sandy clay.	
294 + cms	Coarse sand and gravel.	

BH 253	11.0 m O.D.	NS 7403 9716
0 - 281 cms	Carse, becoming coarser near base.	
281 + cms	Coarse sand and gravel.	

BH 254	11.2 m O.D.	NS 7398 9707
0 - 327 cms	Carse, becoming coarser near base.	
327 + cms	Gravel.	

BH 255	11.6 m O.D.	NS 7392 9701
0 - 22 cms	Moss peat.	
22 - 398 cms	Carse.	
398 - 427 cms	Dark, grey sand.	
427 + cms	Coarse sand and gravel.	

BH 256	12.1 m O.D.	NS 7386 9694
0 - 117 cms	Moss peat.	
117 - 514 cms	Carse, quite sandy in bottom 20-30 cms.	
514 + cms	Gravel.	

BH 257	10.7 m O.D.	NS 7433 9731
0 - 188 cms	Very tough carse.	
188 + cms	Coarse sand.	

BH 258	10.7 m O.D.	NS 7436 9739
0 - 146 cms	Very tough carse.	
146 - 155 cms	Coarse sand and small gravel.	
155 - 195 cms	Blue/grey, silty sand with considerable vegetable matter in top 5-10 cms.	
195 + cms	Small gravel.	

BH 259	10.6 m O.D.	NS 7448 9743
0 - 178 cms	Carse with red and brown staining throughout.	
178 + cms	Coarse sand and gravel.	

BH 260	11.0 m O.D.	NS 7439 9748
0 - 173 cms	Very tough carse.	
173 - 192 cms	Coarse, weathered sand.	
192 - 233 cms	Grey clay, becoming sandier with depth.	
233 + cms	Gravel.	

BH 261	11.0 m O.D.	NS 7443 9755
0 - 166 cms	Very tough carse.	
166 - 172 cms	Gravel with some O.R.S. fragments.	
172 - 225 cms	Grey/brown clay, becoming coarser with depth.	
225 + cms	Gravel.	

BH 262	11.0 m O.D.	NS 7447 9763
0 - 229 cms	Carse, very sandy near base.	
229 + cms	Gravel.	

BH 263	9.8 m O.D.	NS 7448 9769
0 - 100 cms	Carse, very sandy near base.	
100 + cms	Gravel.	

BH 264	11.4 m O.D.	NS 7457 9788
0 - 101 cms	Carse.	
101 - 110 cms	Gravel.	
110 - 141 cms	Carse.	
141 + cms	Red sand and gravel.	

BH 265	11.3 m O.D.	NS 7464 9804
0 - 74 cms	Carse.	
74 - 81 cms	Gravel.	
81 - 96 cms	Carse.	
96 - 113 cms	Tough, grey, silty sand.	
113 - 386 cms	Light grey clay.	
386 + cms	Gravel.	

BH 266		11.3 m O.D.	NS 7461 9799
0 - 98	cms	Carse.	
98 - 105	cms	Gravel.	
105 - 374	cms	Carse.	
374 +	cms	Coarse sand and gravel.	
BH 267		11.2 m O.D.	NS 7458 9794
0 - 95	cms	Carse.	
95 - 112	cms	Coarse sand and big gravel.	
112 - 229	cms	Carse.	
229 +	cms	Coarse, grey sand and gravel.	
BH 268		11.1 m O.D.	NS 7465 9809
0 - 50	cms	Carse.	
50 - 83	cms	Coarse sand and gravel.	
83 - 443	cms	Carse.	
443 +	cms	Dark grey/black, coarse sand.	
BH 269		11.1 m O.D.	NS 7471 9811
0 - 386	cms	Carse - darker near base and including vegetable fragments.	
386 +	cms	Coarse sand and gravel.	
BH 270		11.3 m O.D.	NS 7478 9821
0 - 316	cms	Carse, including peat fragments and 2-3 cms of peaty sand near base.	
316 +	cms	Coarse sand and gravel.	
BH 271		10.0 m O.D.	NS 7481 9826
0 - 234	cms	Carse.	
234 +	cms	Coarse, pink sand and gravel.	
BH 272		9.9 m O.D.	NS 7481 9827
0 - 316	cms	Carse with layers of sand and a peaty band at base.	
316 +	cms	Coarse sand and gravel.	
BH 273		9.9 m O.D.	NS 7483 9828
0 - 90	cms	Carse. Sandy in places.	
90 +	cms	Gravel.	
BH 274		9.9 m O.D.	NS 7485 9832
0 - 86	cms	Carse, with bands of red sand.	
86 +	cms	Coarse, red sand and gravel.	
BH 275		9.9 m O.D.	NS 7486 9834
0 - 85	cms	Carse with bands of red sand.	
85 +	cms	Big gravel, overlain by red sand.	
BH 276		9.8 m O.D.	NS 7488 9838
0 - 78	cms	Carse with bands of red sand.	
78 +	cms	Gravel.	

BH 277		12.1 m O.D.	NS 7383 9686
0 - 91 cms	Peat. Peat/carse mixture near base.		
91 - 542 cms	Carse. Very sandy near base.		
542 + cms	Coarse, grey sand and gravel.		
BH 278		11.3 m O.D.	NS 7379 9679
0 - 492 cms	Carse. Very sandy and shelly at base.		
492 + cms	Coarse sand and gravel.		
BH 279		11.3 m O.D.	NS 7375 9672
0 - 499 cms	Carse. Very sandy and shelly near base. Shell fragments perhaps *Ostrea* or *Mytilus*.		
499 + cms	Coarse, grey sand and gravel.		
BH 280		11.2 m O.D.	NS 7372 9664
0 - 503 cms	Carse. Sandy and shelly near base.		
503 + cms	Coarse sand and gravel.		
BH 281		10.4 m O.D	NS 7368 9657
0 - 448 cms	Carse. Very sandy and shelly in bottom 20-30 cms. Shells perhaps *Ostrea* or *Mytilus*.		
448 + cms	Coarse sand and gravel.		
BH 282		10.4 m O.D.	NS 7366 9653
0 - 443 cms	Carse. Very sandy and shelly at base.		
443 + cms	Gravel. Some thin peat on top.		
BH 283		10.2 m O.D.	NS 7357 9654
0 - 400 cms	Carse. Very sandy near base.		
400 + cms	Coarse sand and gravel.		
BH 284		11.2 m O.D.	NS 7352 9647
0 - 550 cms	Very tough carse.		
550 + cms	Dark grey sand.		
BH 285		11.2 m O.D.	NS 7352 9641
0 - 594 cms	Carse.		
594 + cms	Coarse, tough, dark grey sand.		
BH 286		8.2 m O.D.	NS 7338 9618
0 - 345 cms	Carse. Sand and some shell fragments near base.		
345 + cms	Coarse sand and gravel.		
BH 287		6.7 m O.D.	NS 7328 9606
0 - 104 cms	Carse. Red and sandy in top 20 cms.		
104 - 158 cms	Slightly woody peat.		
158 - 191 cms	Grey, silty clay.		
191 + cms	Light grey, tough, fine sand.		
BH 288		8.7 m O.D.	NS 7327 9606
0 - 335 cms	Carse. Shells at base.		
335 + cms	Light grey sand.		

BH 289	7.5 m O.D.	NS 7329 9610
0 - 87 cms	Carse.	
87 - 104 cms	Peat.	
104 - 364 cms	Grey clay.	
364 - 379 cms	Peat in two bands separated by 2.0 cms of clay.	
379 + cms	Coarse, pinkish/grey sand.	
BH 290	6.5 m O.D.	NS 7329 9604
0 - 73 cms	Carse. Red and sandy at top.	
73 - 212 cms	Peat, mixed with clay from c.190 cms.	
212 - 300 cms	Grey, silty clay. Becoming coarser downwards.	
300 + cms	Coarse, grey sand and small gravel.	
BH 291	9.2 m O.D.	NS 7324 9594
0 - 392 cms	Carse. Very sandy near base.	
392 + cms	Boring stopped by coarse, grey sand.	
BH 292	10.4 m O.D.	NS 7675 9582
0 - 408 cms	Carse, with thin layers of shelly sand from 375 cms downwards.	
408 + cms	Light grey, coarse sand.	
BH 293	10.5 m O.D.	NS 7672 9578
0 - 415 cms	Carse, with thin bands of shelly sand from c.360 cms.	
415 + cms	Pink/grey, coarse sand with rock(?) beneath.	
BH 294	10.5 m O.D.	NS 7669 9575
0 - 315 cms	Carse.	
315 - 336 cms	Peat.	
336 - 352 cms	Grey/green, silty clay.	
352 + cms	Grey/green, silty sand.	
BH 295	10.3 m O.D.	NS 7671 9577
0 - 319 cms	Carse. Shell fragments at base.	
319 - 327 cms	Peat.	
327 - 349 cms	Grey/green, silty clay.	
349 + cms	Grey/green, silty sand.	
BH 296	10.4 m O.D.	NS 7671 9578
0 - 384 cms	Carse.	
384 + cms	Pinkish/grey, coarse sand.	
BH 297	10.3 m O.D.	NS 7671 9578
0 - 316 cms	Carse, shell fragments at base.	
316 - 327 cms	Peat.	
327 - 346 cms	Grey/green, silty clay.	
346 + cms	Grey/green, silty sand.	
BH 298	10.5 m O.D.	NS 7667 9574
0 - 301 cms	Carse.	
301 - 304 cms	Peat.	
304 - 311 cms	Grey, silty clay. Sandy near base.	
311 + cms	Orange/red, silty sand.	

BH 299	10.6 m O.D.	NS 7666 9572
0 - 294 cms	Carse.	
294 - 308 cms	Slightly woody peat.	
308 - 336 cms	Grey, silty clay. Slightly sandy in top 2.0 cms and near base.	
336 + cms	Red sand.	

BH 300	11.5 m O.D.	NS 7664 9569
0 - 23 cms	Red sand and clay.	
23 + cms	Rock.	

BH 301	10.7 m O.D.	NS 7665 9571
0 - 292 cms	Carse, stained red and sandy near top.	
292 - 297 cms	Transition zone.	
297 - 309 cms	Peat.	
309 - 339 cms	Grey/green, silty clay.	
339 + cms	Orange/red sand, very tough.	

BH 302	9.9 m O.D.	NS 7678 9577
0 - 346 cms	Carse. Shell fragments at base.	
346 + cms	Coarse, grey sand.	

BH 303	8.0 m O.D.	NS 7685 9571
0 - 119 cms	Carse.	
119 - 140 cms	Transition zone.	
140 + cms	Grey sand.	

BH 304	8.5 m O.D.	NS 7692 9564
0 - 109 cms	Carse.	
109 - 127 cms	Transition zone.	
127 + cms	Grey sand.	

BH 305	9.4 m O.D.	NS 7691 9559
0 - 321 cms	Tough carse.	
321 + cms	Mixed pink, grey and black sand.	

BH 306	10.0 m O.D.	NS 7687 9558
0 - 234 cms	Carse.	
234 - 246 cms	Peat.	
246 - 262 cms	Grey, silty clay.	
262 + cms	Grey, silty sand.	

BH 307	10.3 m O.D.	NS 7682 9557
0 - 260 cms	Carse.	
260 - 271 cms	Peat.	
271 - 283 cms	Grey/green, silty clay.	
283 + cms	Grey/green, silty sand.	

BH 308	10.3 m O.D.	NS 7679 9556
0 - 240 cms	Carse.	
240 - 244 cms	Transition zone.	
244 - 256 cms	Peat.	
256 - 268 cms	Grey/green, silty clay.	
268 + cms	Grey/green, silty sand.	

BH 309		8.9 m O.D.	NS 7691 9561
0 - 133 cms	Carse. Quite sandy in places.		
133 - 135 cms	Peat.		
135 - 163 cms	Mixture of clay and sand.		
163 + cms	Coarse, grey sand.		
BH 310		9.3 m O.D.	NS 7691 9559
0 - 160 cms	Carse.		
160 - 165 cms	Transition zone.		
165 - 169 cms	Peat.		
169 + cms	Grey, silty sand.		
BH 311		9.8 m O.D.	NS 7688 9558
0 - 204 cms	Carse.		
204 - 208 cms	Slightly woody peat.		
208 + cms	Grey, silty sand.		
BH 312		10.4 m O.D.	NS 7677 9556
0 - 232 cms	Very sandy carse.		
232 - 248 cms	Peat.		
248 - 267 cms	Grey/green, silty clay.		
267 - 272 cms	Grey, silty sand.		
272 + cms	Red sand.		
BH 313		10.8 m O.D.	NS 7678 9556
0 - 54 cms	Red sand.		
54 + cms	Red/brown clay.		
BH 314		11.2 m O.D.	NS 7678 9556
0 - 47 cms	Red sand and clay with stones.		
47 + cms	Rock.		
BH 315		7.9 m O.D.	NS 7664 9594
0 - 272 cms	Carse.		
272 - 331 cms	Black, shelly *(Cardium)*, sand.		
331 + cms	Rock or perhaps big gravel. Sample taken.		
BH 316		9.2 m O.D.	NS 7661 9591
0 - 355 cms	Carse.		
355 + cms	Black, shelly sand.		
BH 317		9.8 m O.D.	NS 7655 9585
0 - 267 cms	Carse.		
267 + cms	Rock or big gravel.		
BH 318		9.8 m O.D.	NS 7648 9579
0 - 268 cms	Carse.		
268 - 285 cms	Peat.		
285 - 329 cms	Grey, silty sand with some clay at top.		
329 + cms	Very coarse, grey sand.		
BH 319		9.9 m O.D.	NS 7652 9584
0 - 223 cms	Carse. Shelly fragments at base.		
223 + cms	Red and grey, shelly sand.		

BH 320	9.8 m O.D.	NS 7649 9581
0 - 228 cms	Carse.	
228 - 265 cms	Grey, shelly clay (carse?) with red sand in top few cms.	
265 - 272 cms	Peat.	
272 + cms	Grey, silty sand.	

BH 321	9.8 m O.D.	NS 7651 9582
0 - 208 cms	Carse.	
208 + cms	Rock, overlain by a thin band of red, shelly sand.	

BH 322	9.4 m O.D.	NS 7644 9575
0 - 103 cms	Carse.	
103 - 121 cms	Shelly clay.	
121 - 146 cms	Carse.	
146 - 164 cms	Peat.	
164 - 273 cms	Grey/blue, silty clay.	
273 - 285 cms	Brown/grey sand.	
285 + cms	Rock.	

BH 323	9.8 m O.D.	NS 7642 9572
0 - 129 cms	Carse.	
129 - 171 cms	Clay/peat mixture.	
171 - 215 cms	Grey, silty clay.	
215 - 230 cms	Peat.	
230 - 236 cms	Grey, silty sand.	
236 + cms	Pink, silty clay.	

BH 324	9.8 m O.D.	NS 7642 9572
0 - 152 cms	Carse with red sand.	
152 - 177 cms	Clay/peat mixture.	
177 - 225 cms	Grey/blue, silty clay.	
225 - 247 cms	Peat.	
247 - 258 cms	Grey, silty clay becoming sandier downwards.	
258 - 262 cms	Red, silty sand.	
262 + cms	Rock.	

BH 325	9.6 m O.D.	NS 7641 9569
0 - 88 cms	Carse.	
88 - 139 cms	Peat (dark brown).	
139 - 206 cms	Grey, silty clay (carse?).	
206 - 220 cms	Peat (light brown).	
220 - 244 cms	Grey, silty clay merging with grey sand at c.229 cms.	
244 + cms	Rock.	

BH 326	7.2 m O.D.	NS 7665 9595
0 - 173 cms	Carse.	
173 - 258 cms	Shelly clay.	
258 + cms	Coarse, grey sand.	

BH 327	7.8 m O.D.	NS 7668 9599
0 - 342 cms	Carse.	
342 + cms	Rock, or big gravel.	

BH 328		7.8 m O.D.	NS 7667 9597
0 - 337	cms	Carse. Becoming sandier downwards and with thin layer of shells at the base.	
337 +	cms	Coarse, grey sand.	
BH 329		7.3 m O.D.	NS 7672 9604
0 - 232	cms	Carse.	
232 +	cms	Rock.	
BH 330		6.7 m O.D.	NS 7676 9611
0 - 214	cms	Carse. Includes shell fragments *(Ostrea?)*.	
214 +	cms	Gravel.	
BH 331		6.7 m O.D.	NS 7679 9618
0 - 370	cms	Tough carse.	
370 +	cms	Gravel.	
BH 332		6.8 m O.D.	NS 7677 9614
0 - 367	cms	Carse. Including some shell fragments.	
367 +	cms	Gravel.	
BH 333		5.8 m O.D.	NS 7682 9627
0 - 173	cms	Fine, red sand.	
173 +	cms	Coarse sand and small gravel.	
BH 334		5.7 m O.D.	NS 7681 9622
0 - 267	cms	Clay/sand mixture in top metre. Normal grey/blue carse below this.	
267 +	cms	Gravel.	
BH 335		9.9 m O.D.	NS 7643 9579
0 - 402	cms	Carse.	
402 +	cms	Rock.	
BH 336		10.4 m O.D.	NS 7637 9567
0 - 322	cms	Carse.	
322 - 335	cms	Peat.	
335 - 352	cms	Grey/green, silty clay.	
352 +	cms	Grey/green, silty sand.	
BH 337		10.5 m O.D.	NS 7639 9561
0 - 283	cms	Carse.	
283 - 292	cms	Peat.	
292 +	cms	Coarse, grey sand.	
BH 338		10.4 m O.D.	NS 7627 9562
0 - 295	cms	Carse.	
295 - 312	cms	Peat.	
312 +	cms	Grey/green, silty sand.	
BH 339		10.5 m O.D.	NS 7618 9556
0 - 463	cms	Carse. Increasingly sandy with depth.	
463 +	cms	Coarse sand and gravel.	

BH 340		10.5 m O.D.	NS 7625 9561
0 - 438 cms	Carse. Coarser and darker with depth.		
438 + cms	Rock or big gravel.		
BH 341		10.3 m O.D.	NS 7629 9563
0 - 302 cms	Carse.		
302 - 319 cms	Peat.		
319 + cms	Grey, silty sand.		
BH 342		10.6 m O.D.	NS 7614 9553
0 - 369 cms	Carse.		
369 - 381 cms	Peat.		
381 + cms	Grey/green, silty sand.		
BH 343		10.3 m O.D.	NS 7618 9557
0 - 421 cms	Carse. Darker and sandier with depth.		
421 + cms	Grey/brown, coarse sand.		
BH 344		10.5 m O.D.	NS 7611 9551
0 - 369 cms	Carse.		
369 + cms	Grey/green, silty sand.		
BH 345		10.4 m O.D.	NS 7605 9547
0 - 322 cms	Carse.		
322 - 341 cms	Transition zone.		
341 - 374 cms	Grey/green, silty clay.		
374 + cms	Grey/green, silty sand.		
BH 346		10.5 m O.D.	NS 7609 9541
0 - 342 cms	Carse. Some peat layers near base.		
342 - 351 cms	Peat.		
351 - 357 cms	Grey/green, silty clay.		
357 + cms	Grey/green, silty sand.		
BH 347		10.8 m O.D.	NS 7627 9595
0 - 488 cms	Carse. Quite dark and sandy near base.		
488 + cms	Rock or big gravel.		
BH 348		10.6 m O.D.	NS 7629 9596
0 - 483 cms	Carse.		
483 + cms	Rock or big gravel.		
BH 349		10.5 m O.D.	NS 7632 9588
0 - 450 cms	Carse. Tougher with depth.		
450 + cms	Rock.		
BH 350		9.2 m O.D.	NS 7641 9578
0 - 204 cms	Carse.		
204 - 220 cms	Peat.		
220 - 262 cms	Grey/green, silty clay. Becoming coarser with depth.		
262 + cms	Grey/green, silty sand.		
BH 351		10.2 m O.D.	NS 7622 9567
0 - 441 cms	Carse. Becoming dark blue/black near base.		
441 + cms	Rock.		

BH 352		10.8 m O.D.	NS 7625 9571
0 - 494	cms	Carse. Becoming tougher with depth.	
494 +	cms	Rock.	
BH 353		10.7 m O.D.	NS 7614 9564
0 - 437	cms	Carse.	
437 +	cms	Grey/brown sand.	
BH 354		10.8 m O.D.	NS 7599 9554
0 - 369	cms	Carse.	
369 - 383	cms	Peat.	
383 - 404	cms	Grey, silty clay.	
404 +	cms	Grey, silty sand.	
BH 355		10.0 m O.D.	NS 7651 9498
0 - 745	cms	Carse. Tougher and darker with depth.	
745 +	cms	Rock or big gravel.	
BH 356		10.2 m O.D.	NS 7643 9506
0 - 443	cms	Carse. Darker and tougher with depth. Shell fragments near base.	
443 +	cms	Rock or big gravel.	
BH 357		10.1 m O.D.	NS 7637 9512
0 - 377	cms	Carse. Very shelly from 377 - c.400 cms.	
377 - 400	cms	Shelly clay.	
400 - 407	cms	Carse.	
407 +	cms	Grey/brown sand.	
BH 358		10.4 m O.D.	NS 7631 9518
0 - 378	cms	Carse. Very shelly from 350 cms down.	
378 +	cms	Grey/brown sand.	
BH 359		10.4 m O.D.	NS 7621 9528
0 - 344	cms	Carse.	
344 - 357	cms	Peat. Mixed with clay.	
357 - 383	cms	Grey/green, silty sand with a considerable proportion of clay in top 10 cms.	
383 +	cms	Grey/brown sand.	
BH 360		10.4 m O.D.	NS 7624 9523
0 - 335	cms	Carse. Shell fragments at base.	
335 - 348	cms	Peat. Mixed with clay in part.	
348 - 372	cms	Grey/green, silty sand. Some clay in top 10-15 cms.	
372 +	cms	Grey/brown sand.	
BH 361		10.5 m O.D.	NS 7627 9521
0 - 351	cms	Carse. Very shelly near base.	
351 - 352	cms	Peat.	
352 - 359	cms	Grey, silty clay. Some shell fragments at top.	
359 - 367	cms	Grey/green, silty clay.	
367 +	cms	Grey/brown sand.	

BH 362	10.7 m O.D.	NS 7628 9519
0 - 406 cms	Carse. Becoming tougher and sandier with depth.	
406 + cms	Grey/brown sand.	
BH 363	9.7 m O.D.	NS 7658 9489
0 - 731 cms	Carse. Becoming blue/black and slightly tougher with depth.	
731 + cms	Dark pink, clayey sand with some stones.	
BH 364	10.3 m O.D.	NS 7662 9482
0 - 550+ cms	Tough, black carse.	
BH 365	10.0 m O.D.	NS 7666 9476
0 - 470+ cms	Tough carse.	
BH 366	8.0 m O.D.	NS 7671 9469
0 - 270+ cms	Tough carse. Increasingly sandy with depth.	
BH 367	9.7 m O.D.	NS 7668 9747
0 - 650+ cms	Tough carse. Tougher and sandier with depth.	
BH 368	9.8 m O.D.	NS 7664 9739
0 - 500+ cms	Tough carse. Tougher and sandier with depth.	
BH 369	10.2 m O.D.	NS 7654 9742
0 - 550+ cms	Tough carse. Tougher and coarser with depth.	
BH 370	9.8 m O.D.	NS 7641 9732
0 - 650+ cms	Very tough carse.	
BH 371	7.4 m O.D.	NS 7633 9728
0 - 398 cms	Very tough carse.	
398 + cms	Gravel.	
BH 372	10.0 m O.D.	NS 7647 9719
0 - 460+ cms	Very tough carse.	
BH 373	9.3 m O.D.	NS 7661 9731
0 - 410+ cms	Very tough carse.	
BH 374	Not Levelled	NS 7714 9727
0 - 550+ cms	Tough carse. Mixed with peat in top 50 cms.	
BH 375	12.4 m O.D.	NS 8179 9655
0 - 185 cms	Very soft carse.	
185 - 232 cms	Soft, brown peat.	
232 + cms	Coarse, grey/brown sand.	
BH 376	12.5 m O.D.	NS 8181 9651
0 - 210 cms	Very soft carse.	
210 - 282 cms	Peat.	
282 + cms	Orange/brown sand with small gravel.	

BH 377	12.4 m O.D.	NS 8181 9641
0 - 222 cms	Carse. Some red sand in places but otherwise very soft.	
222 - 316 cms	Peat.	
316 - 322 cms	Grey/brown sand.	
322 + cms	Pink, silty sand.	

BH 378	12.4 m O.D.	NS 8179 9643
0 - 229 cms	Carse.	
229 - 315 cms	Peat.	
315 + cms	Grey/brown sand.	

BH 379	12.4 m O.D.	NS 8181 9634
0 - 314 cms	Carse. Quite sandy near base.	
314 - 424 cms	Peat. Very tough and woody. Mixed with grey clay near base.	
424 + cms	Pink, silty sand.	

BH 380	11.7 m O.D.	NS 8183 9627
0 - 180 cms	Carse.	
180 - 282 cms	Peat. Woody in places.	
282 - 290 cms	Brown sand.	
290 + cms	Pink clay. Slightly grey in top few cms.	

BH 381	11.6 m O.D.	NS 8185 9615
0 - 248 cms	Carse.	
248 - 320 cms	Peat.	
320 - 345 cms	Grey/green, silty sand.	
345 + cms	Pink clay.	

BH 382	11.9 m O.D.	NS 8183 9621
0 - 251 cms	Carse.	
251 - 343 cms	Peat. Woody on top.	
343 - 354 cms	Grey/green, silty clay. Very light in colour.	
354 + cms	Pink clay.	

BH 383	12.0 m O.D.	NS 8189 9611
0 - 309 cms	Carse.	
309 - 351 cms	Peat.	
351 - 362 cms	Light grey/green clay.	
362 - 373 cms	Pink clay.	
373 + cms	Reddish/pink sand.	

BH 384	12.1 m O.D.	NS 8191 9602
0 - 342 cms	Carse.	
342 - 356 cms	Peat.	
356 - 368 cms	Light grey/green clay.	
368 + cms	Pink clay.	

BH 385	12.0 m O.D.	NS 8194 9591
0 - 346 cms	Carse.	
346 - 368 cms	Peat.	
368 - 385 cms	Light grey/green, silty sand.	
385 + cms	Pink, silty sand.	

BH 386	11.3 m O.D.	NS 8198 9581
0 - 328 cms	Carse.	
328 - 336 cms	Peat.	
336 - 360 cms	Light grey/green, silty sand.	
360 + cms	Pink, silty sand.	

BH 387	10.8 m O.D.	NS 8199 9573
0 - 284 cms	Carse.	
284 - 296 cms	Peat.	
296 + cms	Light grey, silty sand.	

BH 388	10.4 m O.D.	NS 8202 9562
0 - 353 cms	Carse.	
353 - 382 cms	Very woody peat.	
382 - 417 cms	Light grey/green clay.	
417 + cms	Pink, silty sand. Quite clayey at top.	

BH 389	9.5 m O.D.	NS 8204 9548
0 - 324 cms	Carse.	
324 - 348 cms	Very tough peat.	
348 - 381 cms	Grey/green, silty sand.	
381 + cms	Pink, silty sand.	

BH 390	9.4 m O.D.	NS 8206 9541
0 - 372 cms	Carse.	
372 - 389 cms	Peat.	
389 + cms	Grey/green, silty sand.	

BH 391	9.6 m O.D.	NS 8205 9545
0 - 410 cms	Carse.	
410 - 432 cms	Peat.	
432 + cms	Grey/green, silty sand with clay on top.	

BH 392	9.3 m O.D.	NS 8208 9532
0 - 354 cms	Carse.	
354 - 367 cms	Peat.	
367 + cms	Grey, silty sand.	

BH 393	9.3 m O.D.	NS 8211 9524
0 - 502 cms	Carse. Very tough and sandy in places.	
502 - 504 cms	Peat.	
504 + cms	Grey, silty sand.	

BH 394	9.2 m O.D.	NS 8209 9528
0 - 355 cms	Carse.	
355 - 366 cms	Clay/peat mixture.	
366 - 378 cms	Grey, silty sand.	
378 + cms	Brown/pink, silty sand.	

BH 395	9.2 m O.D.	NS 8212 9519
0 - 346 cms	Carse.	
346 - 348 cms	Peat.	
348 + cms	Grey, silty sand. Slightly pink in top 5-10 cms.	

BH 396	8.4 m O.D.	NS 8214 9509
0 - 273 cms	Carse, very tough and sandy in places, black.	
273 + cms	Orange/red, silty sand. Peat at base. Still present at 315 cms where it is less orange and more grey.	
BH 397	8.9 m O.D.	NS 8213 9514
0 - 325 cms	Carse. Sandy and tough.	
325 - 327 cms	Clay/peat mixture.	
327 + cms	Very tough, grey/brown, silty sand.	
BH 398	5.9 m O.D.	NS 8213 9503
0 - 400+ cms	Carse. Contains layers of varying toughness.	
BH 399	4.4 m O.D.	NS 8207 9488
0 - 397 cms	Carse. Very soft at top but containing bands of fine sand which increase in frequency from c.300 cms and make penetration difficult beyond c.390 cms.	
397 + cms	Gravel.	
BH 400	4.8 m O.D.	NS 8205 9495
0 - 436 cms	Carse. Sandy from top but sandy nature and toughness increase downwards.	
436 + cms	Gravel.	
BH 401	4.6 m O.D.	NS 8214 9477
0 - 467 cms	Carse. Quite sandy in places.	
467 + cms	Grey/brown sand.	
BH 402	4.7 m O.D.	NS 8228 9471
0 - 450 cms	Carse.	
450 + cms	Grey/brown sand.	
BH 403	8.6 m O.D.	NS 8556 9601
0 - 70 cms	Fine sand.	
70 - 443 cms	Deposit still very sandy but containing clay which increases in proportion downwards.	
443 + cms	Gravel.	
BH 404	8.9 m O.D.	NS 8557 9595
0 - 156 cms	Carse. Tough and sandy.	
156 - 171 cms	Sand and small gravel.	
171 + cms	Pink, silty sand.	
BH 405	9.5 m O.D.	NS 8559 9592
0 - 93 cms	Carse. Quite sandy and very tough.	
93 + cms	Coarse, orange/red sand.	
BH 406	9.6 m O.D.	NS 8561 9588
0 - 70 cms	Carse. Very sandy and tough.	
70 - 93 cms	Coarse, orange/brown sand.	
93 + cms	Gravel.	
BH 407	9.5 m O.D.	NS 8558 9594
0 - 98 cms	Carse. Very tough and sandy.	
98 + cms	Coarse, red/brown sand and small gravel.	

BH 408		8.8 m O.D.	NS 8571 9596
0 - 55	cms	Fine sand.	
55 - 312	cms	Fine sand and clay.	
312 +	cms	Gravel.	
BH 409		9.0 m O.D.	NS 8572 9593
0 - 61	cms	Mixture of sand and very little clay.	
61 +	cms	Gravel.	
BH 410		9.6 m O.D.	NS 8574 9588
0 - 63	cms	Sand/clay mixture.	
63 +	cms	Weathered orange and white sandstone, suggesting rock beneath.	
BH 411		12.6 m O.D.	NS 8521 9662
0 - 70	cms	Sandy carse.	
70 +	cms	Grey sand, giving way to a mixture of grey and pink sand with small gravel.	
BH 412		12.0 m O.D.	NS 8522 9659
0 - 87	cms	Carse.	
87 +	cms	Grey/brown sand and tightly packed gravel.	
BH 413		11.2 m O.D.	NS 8524 9651
0 - 20	cms	Sandy clay.	
20 +	cms	Tough gravel.	
BH 414		11.1 m O.D.	NS 8525 9649
0 - 49	cms	Brown sand with surface clay.	
49 +	cms	Tough gravel.	
BH 415		10.6 m O.D.	NS 8529 9644
0 - 95	cms	Red/brown sand with considerable proportion of clay and some stones at top.	
95 +	cms	Coarse sand and gravel.	
BH 416		10.2 m O.D.	NS 8532 9639
0 - 72	cms	Red/brown sand with clay.	
72 - 172	cms	Carse-clay.	
172 - 176	cms	Peat.	
176 - 185	cms	Grey clay with some sand and small stones.	
185 +	cms	Gravel and coarse, pink sand.	
BH 417		10.4 m O.D.	NS 8531 9641
0 - 68	cms	Red/brown, fine sand.	
68 +	cms	Gravel.	
BH 418		10.3 m O.D.	NS 8531 9641
0 - 60	cms	Red/brown sand with some clay.	
60 - 177	cms	Light grey (carse) clay.	
177 - 181	cms	Peat.	
181 - 193	cms	Grey clay containing vegetable fragments and becoming sandier with depth.	
193 +	cms	Gravel.	

BH 419	8.9 m O.D.	NS 8536 9629
0 - 102 cms	Grey/brown, sandy clay becoming coarser downwards.	
102 - 121 cms	Small gravel.	
121 - 134 cms	Grey clay.	
134 - 170 cms	Pink, silty sand.	
170 + cms	Gravel.	

BH 420	9.6 m O.D.	NS 8534 9634
0 - 51 cms	Red/brown sand.	
51 - 171 cms	Grey (carse) clay.	
171 - 180 cms	Pink, silty sand.	
180 + cms	Gravel.	

BH 421	9.9 m O.D.	NS 8532 9636
0 - 67 cms	Red/brown sand.	
67 - 166 cms	Grey (carse) clay.	
166 - 172 cms	Peat. Woody near base.	
172 - 177 cms	Grey, silty sand.	
177 - 179 cms	Pink sand.	
179 + cms	Gravel.	

BH 422	8.6 m O.D.	NS 8537 9625
0 - 73 cms	Red/brown, sandy clay.	
73 - 140 cms	Pink sand and small gravel with a considerable proportion of clay.	
140 - 169 cms	Coarse sand and small gravel. Wet and easily penetrated.	
169 - 178 cms	Sand and peat mixture.	
178 - 180 cms	Grey clay.	
180 - 219 cms	Exceedingly wet, brown sand.	
219 + cms	Gravel, possibly overlain by a thin band of grey clay.	

BH 423	8.3 m O.D.	NS 8539 9621
0 - 56 cms	Clay/sand mixture.	
56 + cms	Tough gravel.	

BH 424	8.4 m O.D.	NS 8538 9623
0 - 78 cms	Clay with a considerable proportion of sand.	
78 + cms	Pink sand and small gravel.	

BH 425	8.2 m O.D.	NS 8539 9617
0 - 149 cms	Clay/sand mixture.	
149 - 206 cms	Pink/grey, sandy silt with vegetable fragments in places.	
206 - 219 cms	Peat/clay mixture.	
219 - 230 cms	Coarse sand and gravel, grey in colour and very wet.	
230 - 260 cms	Grey sand with thin band of grey clay on top. Occasional stones.	
260 + cms	Pink, silty sand.	

BH 426	8.6 m O.D.	NS 8539 9612
0 - 160+ cms	Red/brown, sandy clay.	

BH 427		8.2 m O.D.	NS 8633 9368
0 - 194 cms	Carse-clay. Band of shells at 120-125 cms mostly *Cardium*. Quite sandy from 150 cms with *Ostrea* and *Mytilus* fragments.		
194 - 247 cms	Peat. Woody near base.		
247 - 297 cms	Grey/green, silty clay.		
297 - 411 cms	Grey, silty sand.		
411 + cms	Gravel.		
BH 428		8.1 m O.D.	NS 8632 9365
0 - 202 cms	Carse. Very sandy and rich in shell fragments *(Ostrea)* between 190 and 200 cms.		
202 - 251 cms	Peat. Woody in places.		
251 - 298 cms	Grey/green, silty clay.		
298 + cms	Grey, silty sand.		
BH 429		8.2 m O.D.	NS 8631 9359
0 - 224 cms	Carse. Sandy in places.		
224 - 282 cms	Peat. Very woody near base.		
282 - 327 cms	Grey, silty clay.		
327 + cms	Grey, silty sand.		
BH 430		7.5 m O.D.	NS 8628 9351
0 - 219 cms	Carse.		
219 - 254 cms	Peat. Tree at top.		
254 - 347 cms	Grey, silty clay.		
347 + cms	Grey, silty sand.		
BH 431		6.9 m O.D.	NS 8623 9344
0 - 306 cms	Carse. Quite tough at top.		
306 + cms	Grey, silty sand.		
BH 432		7.2 m O.D.	NS 8626 9347
0 - 240 cms	Carse.		
240 - 252 cms	Shelly sand.		
252 - 255 cms	Grey clay.		
255 - 256 cms	Peat.		
256 - 333 cms	Grey clay.		
333 + cms	Grey, silty sand.		
BH 433		7.2 m O.D.	NS 8627 9349
0 - 232 cms	Carse. Quite sandy in places and shelly in bottom 10-15 cms.		
232 - 253 cms	Peat.		
253 - 304 cms	Grey/green, silty clay.		
304 + cms	Grey, silty sand.		
BH 434		6.2 m O.D.	NS 8621 9341
0 - 250+ cms	Carse. Includes shelly sand *(Ostrea)* 250-260 cms. Becomes sandier downwards merging with the grey sand somewhere about 250-300 cms.		
BH 435		6.7 m O.D.	NS 8622 9343
0 - 283 cms	Carse. Becomes very sandy downwards.		
283 + cms	Grey, silty sand. Very rich in mica.		

BH 436	6.7 m O.D.	NS 8619 9332
0 - 465+ cms	Carse. Becomes tougher and darker downwards, penetration not being possible beyond 465 cms where carse-clay is blue/grey with shells.	

BH 437	3.1 m O.D.	NS 8617 9326
0 - 98 cms	Grey/brown clay with abundant vegetable remains.	
98 - 105 cms	Red/brown, coarse sand.	
105 - 116 cms	Grey, coarse sand.	
116 + cms	Intermixed layers of dark blue/black clay and sand. Some shells *(Mytilus)*.	

BH 438	3.0 m O.D.	NS 8613 9319
0 - 107 cms	Grey/brown clay.	
107 - 422 cms	Dark blue/black clay. Includes layers of grey sand and becomes coarser and tougher downwards.	
422 + cms	Gravel.	

BH 439	8.2 m O.D.	NS 8637 9389
0 - 191 cms	Carse.	
191 - 259 cms	Peat. Woody in places.	
259 - 350 cms	Grey clay.	
350 + cms	Pink, silty sand and small gravel.	

BH 440	7.9 m O.D.	NS 8635 9385
0 - 178 cms	Carse.	
178 - 242 cms	Peat.	
242 - 302 cms	Grey/green, silty clay.	
302 - 372 cms	Grey, silty sand.	
372 + cms	Rock or big gravel.	

BH 441	7.9 m O.D.	NS 8634 9378
0 - 184 cms	Carse. Shell fragments at 80-90 cms. Mainly *Cardium* but with *Mytilus*.	
184 - 237 cms	Peat mixed somewhat with clay in top few cms.	
237 - 323 cms	Grey/green, silty clay.	
323 - 379 cms	Grey, silty sand.	
379 + cms	Gravel.	

BH 442	7.0 m O.D.	NS 8593 9401
0 - 175 cms	Carse.	
175 - 206 cms	Peat. Woody at top.	
206 - 244 cms	Grey, silty clay.	
244 + cms	Grey, silty sand.	

BH 443	8.1 m O.D.	NS 8629 9394
0 - 151 cms	Carse.	
151 - 162 cms	Transition zone.	
162 - 230 cms	Woody peat.	
230 - 314 cms	Grey clay.	
314 + cms	Pink sand and small gravel.	

BH 444	7.9 m O.D.	NS 8628 9392
0 - 137 cms	Carse.	
137 - 154 cms	Transition zone.	
154 - 216 cms	Peat.	
216 - 314 cms	Grey clay.	
314 + cms	Pink, silty sand and small gravel.	

BH 445	7.6 m O.D.	NS 8627 9391
0 - 138 cms	Carse.	
138 - 151 cms	Transition zone.	
151 - 198 cms	Peat.	
198 - 267 cms	Grey clay.	
267 - 294 cms	Grey, silty sand. Very tough.	
294 + cms	Pink, silty sand and small gravel.	

BH 446	8.1 m O.D.	NS 8630 9398
0 - 135 cms	Carse.	
135 - 152 cms	Transition zone.	
152 - 221 cms	Peat.	
221 - 294 cms	Grey clay. Coarser with depth.	
294 + cms	Big gravel and grey sand.	

BH 447	7.8 m O.D.	NS 8621 9397
0 - 138 cms	Carse.	
138 - 147 cms	Transition zone.	
147 - 205 cms	Peat.	
205 - 291 cms	Grey clay.	
291 + cms	Gravel.	

BH 448	7.7 m O.D.	NS 8619 9395
0 - 126 cms	Carse.	
126 - 152 cms	Transition zone.	
152 - 213 cms	Peat.	
213 - 262 cms	Grey (silty) clay.	
262 - 340 cms	Grey, silty sand. Slightly pink near base.	
340 + cms	Tough, plastic, pink, silty sand and small gravel.	

BH 449	7.0 m O.D.	NS 8618 9391
0 - 223 cms	Carse.	
223 + cms	Rock or big gravel.	

BH 450	7.4 m O.D.	NS 8607 9396
0 - 266 cms	Carse.	
266 + cms	Rock or big gravel(?).	

BH 451	7.7 m O.D.	NS 8608 9398
0 - 323 cms	Carse.	
323 + cms	Sand and gravel overlain by relatively thin layer of grey, silty sand.	

BH 452	8.2 m O.D.	NS 8609 9401
0 - 173 cms	Carse.	
173 - 209 cms	Clay/peat mixture (including reed heads).	
209 - 264 cms	Peat.	
264 - 328 cms	Grey clay.	
328 - 346 cms	Grey, silty sand and some small gravel near base.	
346 + cms	Coarse, pink, silty sand and small gravel.	

BH 453	8.4 m O.D.	NS 8611 9403
0 - 170 cms	Carse.	
170 - 205 cms	Transition zone.	
205 - 269 cms	Peat.	
269 - 313 cms	Grey clay.	
313 - 319 cms	Grey, silty sand.	
319 + cms	Coarse, pink, silty sand and small gravel.	

BH 454	8.3 m O.D.	NS 8596 9409
0 - 70 cms	Carse.	
70 + cms	Boring stopped by broken rock fragments (Rockhead? or Fill?).	

BH 455	7.9 m O.D.	NS 8595 9408
0 - 170 cms	Carse.	
170 - 199 cms	Transition zone.	
199 - 251 cms	Peat. Mixed with lenses of clay near base.	
251 - 261 cms	Grey, silty clay.	
261 - 279 cms	Grey, silty sand.	
279 + cms	Pink, silty sand and small gravel.	

BH 456	7.3 m O.D.	NS 8594 9404
0 - 151 cms	Carse.	
151 - 160 cms	Transition zone.	
160 - 191 cms	Peat.	
191 - 232 cms	Grey, silty clay.	
232 - 258 cms	Tough, grey, silty sand.	
258 + cms	Tough, pink, silty sand.	

BH 457	8.5 m O.D.	NS 8641 9388
0 - 225 cms	Carse.	
225 - 294 cms	Peat.	
294 - 377 cms	Grey clay. Slightly sandier near base.	
377 + cms	Coarse, pink sand and small gravel.	

BH 458	8.6 m O.D.	NS 8672 9381
0 - 88 cms	Carse.	
88 - 178 cms	Peat.	
178 + cms	Grey/brown sand.	

BH 459	8.7 m O.D.	NS 8666 9383
0 - 89 cms	Carse.	
89 - 121 cms	Coarse sand and gravel. Loosely packed.	
121 - 176 cms	Peat.	
176 - 320 cms	Grey clay/sand mixed considerably with peat in top 5-6 cms.	
320 + cms	Coarse sand and gravel.	

BH 460	9.1 m O.D.	NS 8662 9381
0 - 133 cms	Carse.	
133 - 156 cms	Coarse sand and sandstone gravel. Loosely packed.	
156 - 286 cms	Grey clay (carse?).	
286 - 363 cms	Peat.	
363 - 460 cms	Grey clay.	
460 + cms	Coarse, pink, silty sand and small gravel.	

BH 461	8.8 m O.D.	NS 8661 9377
0 - 146 cms	Carse.	
146 - 166 cms	Coarse sand and gravel. Some shells near base.	
166 - 267 cms	Grey clay (carse?).	
267 - 328 cms	Peat.	
328 - 463 cms	Grey clay.	
463 + cms	Grey/pink, tough, silty sand.	

BH 462	8.4 m O.D.	NS 8659 9368
0 - 155 cms	Carse.	
155 - 170 cms	Coarse sand and gravel with shells.	
170 - 251 cms	Grey clay (carse?).	
251 - 259 cms	Transition zone.	
259 - 315 cms	Peat.	
315 - 458 cms	Grey clay.	
458 + cms	Grey, slightly pink, silty sand.	

BH 463	9.3 m O.D.	NS 8664 9386
0 - 123 cms	Carse. Sandy with depth.	
123 - 159 cms	Coarse sand and gravel.	
159 - 228 cms	Grey clay (carse?).	
228 - 382 cms	Peat. Quite woody.	
382 - 453 cms	Grey clay. Slightly pink near base.	
453 + cms	Rock or big gravel.	

BH 464	10.0 m O.D.	NS 8658 9387
0 - 175 cms	Carse. Increasing sandy beyond 100 cms.	
175 + cms	Coarse sand and gravel. Tightly packed.	

BH 465	9.7 m O.D.	NS 8656 9386
0 - 232 cms	Carse.	
232 - 383 cms	Peat.	
383 - 497 cms	Grey clay.	
497 + cms	Pink, silty sand and small gravel.	

BH 466	8.9 m O.D.	NS 8650 9388
0 - 245 cms	Carse.	
245 - 344 cms	Very woody peat.	
344 - 427 cms	Grey clay. Coarser near base.	
427 + cms	Pink, silty sand and small gravel.	

BH 467	8.5 m O.D.	NS 8645 9389
0 - 210 cms	Carse.	
210 - 223 cms	Transition zone.	
223 - 301 cms	Peat.	
301 - 376 cms	Grey clay. Tougher near base.	
376 + cms	Coarse, pink sand and small gravel.	

BH 468		9.7 m O.D.	NS 9123 9112
0 - 150	cms	Carse. Very sandy, with stones near base.	
150 +	cms	Rock.	
BH 469		9.4 m O.D.	NS 9123 9111
0 - 172	cms	Carse. Very sandy and stoney.	
172 +	cms	Rock (Sandstone?).	
BH 470		8.4 m O.D.	NS 9123 9108
0 - 100	cms	Carse.	
100 - 133	cms	Coarse, yellow/brown sand.	
133 - 202	cms	Carse-clay. Quite sandy.	
202 +	cms	Coal(?). Quite soft in top few centimetres.	
BH 471		7.5 m O.D.	NS 9122 9104
0 - 101	cms	Carse, with sand layers and stones.	
101 +	cms	Rock (Sandstone?).	
BH 472		7.8 m O.D.	NS 9135 9105
0 - 173	cms	Carse. Very sandy and stoney near base.	
173 +	cms	Rock (Sandstone?).	
BH 473		7.2 m O.D.	NS 9122 9099
0 - 102	cms	Carse.	
102 +	cms	Rock.	
BH 474		7.1 m O.D.	NS 9123 9009
0 - 118	cms	Carse. Shell fragments at base.	
118 +	cms	Rock.	
BH 475		6.5 m O.D.	NS 9121 9092
0 - 256	cms	Carse. Slightly coarser with depth.	
256 +	cms	Rock.	
BH 476		5.9 m O.D.	NS 9119 9083
0 - 289	cms	Carse. Some shells near base.	
289 +	cms	Rock.	
BH 477		6.2 m O.D.	NS 9117 9074
0 - 358	cms	Carse. Tough, very shelly near base.	
358 +	cms	Rock.	
BH 478		5.5 m O.D.	NS 9115 9063
0 - 368	cms	Carse.	
368 +	cms	Tough, chocolate brown sand.	
BH 479		5.8 m O.D.	NS 9116 9069
0 - 384	cms	Carse.	
384 +	cms	Very tough, grey/brown sand.	
BH 480		6.1 m O.D.	NS 9117 9072
0 - 401	cms	Carse. Shells near base.	
401 +	cms	Rock.	

BH 481	5.5 m O.D.	NS 9115 9059
0 - 347 cms	Carse. Shells near base.	
347 + cms	Rock.	
BH 482	5.8 m O.D.	NS 9116 9063
0 - 416 cms	Carse. Quite tough with shells near base.	
416 + cms	Chocolate brown sand.	
BH 483	5.6 m O.D.	NS 9113 9051
0 - 422 cms	Carse. Very sandy near base with numerous shells.	
422 + cms	Broken or rotted rock.	
BH 484	5.5 m O.D.	NS 9112 9043
0 - 446 cms	Carse. Quite tough. Very black and shelly near base.	
446 + cms	Rock.	
BH 485	5.4 m O.D.	NS 9109 9035
0 - 410 cms	Carse. Very tough with thick shell bed in lower 50 cms.	
410 + cms	Rock.	
BH 486	4.4 m O.D.	NS 9108 9017
0 - 549 cms	Carse.	
549 + cms	Coarse, grey sand and shell fragments.	
BH 487	4.5 m O.D.	NS 9108 9008
0 - 550+ cms	Very tough carse.	
BH 488	4.2 m O.D.	NS 9108 9029
0 - 402 cms	Carse. Shelly and sandy near base.	
402 + cms	Broken rock and coarse, grey sand.	
BH 489	10.9 m O.D.	NS 8273 9604
0 - 337 cms	Carse.	
337 - 353 cms	Peat.	
353 - 361 cms	Soft, grey clay.	
361 + cms	Tough, grey/green, silty sand.	
BH 490	11.6 m O.D.	NS 8269 9604
0 - 407 cms	Carse.	
407 - 418 cms	Peat.	
418 - 451 cms	Tough, grey/green, silty sand.	
451 + cms	Pink, silty sand.	
BH 491	11.6 m O.D.	NS 8267 9608
0 - 394 cms	Very tough carse.	
394 - 403 cms	Peat.	
403 + cms	Grey/green, silty sand. Boring stopped at 454 cms by toughness of deposit. Pink clay may have been present in end of borer.	

BH 492		11.6 m O.D.	NS 8263 9612
0 - 396	cms	Extremely tough carse.	
396 - 407	cms	Peat.	
407 - 439	cms	Grey/green, silty sand.	
439 +	cms	Pink, silty sand.	
BH 493		10.6 m O.D.	NS 8259 9615
0 - 356	cms	Tough carse. Quite soft near base.	
356 - 381	cms	Dark grey sand.	
381 +	cms	Pink sand with small stones.	
BH 494		9.9 m O.D.	NS 8253 9609
0 - 329	cms	Carse.	
329 - 352	cms	Light grey, silty sand.	
352 +	cms	Grey, silty sand with stones.	
BH 495		10.3 m O.D.	NS 8254 9607
0 - 466	cms	Carse.	
466 +	cms	Coarse, pink/grey sand and gravel.	
BH 496		10.5 m O.D.	NS 8255 9605
0 - 461	cms	Carse.	
461 +	cms	Coarse, pink sand.	
BH 497		10.4 m O.D.	NS 8253 9604
0 - 294	cms	Carse.	
294 - 299	cms	Peat.	
299 - 328	cms	Grey/green, micaceous, silty sand.	
328 +	cms	Pink, silty sand.	
BH 498		10.3 m O.D.	NS 8249 9603
0 - 298	cms	Carse.	
298 +	cms	Grey/green, silty sand.	
BH 499		9.3 m O.D.	NS 8245 9602
0 - 357	cms	Carse.	
357 +	cms	Coarse, pink sand and small gravel.	
BH 500		9.7 m O.D.	NS 8251 9606
0 - 251	cms	Carse.	
251 +	cms	Tough, brown/grey sand.	
BH 501		9.9 m O.D.	NS 8246 9598
0 - 261	cms	Carse.	
261 - 264	cms	Peat (mixed with clay).	
264 - 289	cms	Grey/green, silty sand.	
289 +	cms	Grey/pink, silty sand, with some coarse, pink sand.	
BH 502		9.2 m O.D.	NS 8239 9592
0 - 200	cms	Carse. Mixed with some peat near base.	
200 - 248	cms	Grey/green, silty sand.	
248 +	cms	Pink, silty sand.	

BH 503		9.0 m O.D.	NS 8243 9596
0 - 153 cms	Carse.		
153 + cms	Grey, silty sand. Dark near top, lighter downwards.		
BH 504		8.9 m O.D.	NS 8243 9594
0 - 169 cms	Carse.		
169 - 173 cms	Clay/peat mixture.		
173 + cms	Grey/green, silty sand.		
BH 505		9.4 m O.D.	NS 8245 9599
0 - 291 cms	Carse.		
291 + cms	Dark grey, silty sand.		
BH 506		10.4 m O.D.	NS 8251 9598
0 - 353+ cms	Very sandy carse.		
BH 507		10.2 m O.D.	NS 8253 9598
0 - 271 cms	Carse.		
271 - 279 cms	Transition zone.		
279 - 284 cms	Peat.		
284 - 319 cms	Grey/green, silty sand.		
319 + cms	Pink, silty sand.		
BH 508		10.4 m O.D.	NS 8257 9598
0 - 281 cms	Carse.		
281 - 290 cms	Peat.		
290 + cms	Grey/green, silty sand.		
BH 509		10.1 m O.D.	NS 8259 9598
0 - 456 cms	Carse.		
456 + cms	Coarse, pink sand.		
BH 510		10.0 m O.D.	NS 8259 9589
0 - 562 cms	Carse. Shells from 500 cms to base.		
562 + cms	Pink sand and some gravel.		
BH 511		10.0 m O.D.	NS 8256 9589
0 - 335 cms	Carse.		
335 - 346 cms	Peat (mixed with clay on top and silty sand on bottom).		
346 + cms	Grey/green, silty sand.		
BH 512		9.5 m O.D.	NS 8258 9581
0 - 337 cms	Carse.		
337 - 355 cms	Peat.		
355 + cms	Grey/green, silty sand.		
BH 513		9.4 m O.D.	NS 8258 9572
0 - 356 cms	Carse.		
356 - 363 cms	Peat.		
363 + cms	Grey/green, clayey sand.		

BH 514		9.3 m O.D.	NS 8258 9567
0 - 347 cms	Carse.		
347 - 353 cms	Peat.		
353 + cms	Grey/green, silty sand.		
BH 515		9.4 m O.D.	NS 8258 9565
0 - 356 cms	Carse.		
356 - 373 cms	Peat.		
373 + cms	Grey/green, silty sand with some clay.		
BH 516		8.4 m O.D.	NS 8258 9562
0 - c310 cms	Carse.		
310 - 366 cms	Grey, silty sand and clay.		
366 + cms	Grey/brown to pink, silty sand.		
BH 517		9.5 m O.D.	NS 8252 9563
0 - 477+ cms	Carse. Increasingly sandy with depth.		
BH 518		9.4 m O.D.	NS 8248 9563
0 - 534 cms	Carse. Increasingly tough and sandy with depth.		
534 + cms	Coarse sand and gravel (Sandstone and coal fragments).		
BH 519		9.2 m O.D.	NS 8249 9554
0 - 400+ cms	Carse. Tough and sandy with depth.		
BH 520		9.3 m O.D.	NS 8248 9565
0 - 550 cms	Very coarse carse.		
550 + cms	Small gravel.		
BH 521		9.5 m O.D.	NS 8251 9568
0 - 481+ cms	Carse. Increasingly tough and sandy with depth.		
BH 522		Not Levelled	NS 8311 9597
0 - 378 cms	Carse.		
378 - 393 cms	Very tough clay/peat mixture.		
393 - 407 cms	Peat.		
407 - 430 cms	Grey/green, silty sand.		
430 + cms	Very tough, pink, silty sand.		
BH 523		Not Levelled	NS 8314 9591
0 - 331 cms	Carse.		
331 - 338 cms	Clay/peat mixture.		
338 - 353 cms	Peat.		
353 + cms	Grey/green, silty sand.		
BH 524		12.0 m O.D.	NS 8158 9617
0 - 70 cms	Carse.		
70 - 133 cms	Soft peat.		
133 + cms	Coarse, brown sand and gravel.		
BH 525		12.2 m O.D.	NS 8157 9617
0 - 65 cms	Carse.		
65 - 92 cms	Peat.		
92 + cms	Coarse sand and gravel.		

BH 526		11.9 m O.D.	NS 8159 9616
0 - 75	cms	Carse.	
75 - 169	cms	Soft peat.	
169 +	cms	Coarse, brown sand and gravel.	
BH 527		12.0 m O.D.	NS 8162 9616
0 - 121	cms	Carse.	
121 - 213	cms	Soft, woody peat.	
213 - 271	cms	Brown/pink, silty sand.	
271 +	cms	Coarse sand and gravel.	
BH 528		11.9 m O.D.	NS 8161 9616
0 - 96	cms	Carse.	
96 - 201	cms	Peat.	
201 - 254	cms	Pink, silty sand.	
254 +	cms	Gravel.	
BH 529		12.0 m O.D.	NS 8164 9615
0 - 168	cms	Carse.	
168 - 258	cms	Peat.	
258 - 288	cms	Pink, silty sand.	
288 +	cms	Coarse, pink sand and small gravel.	
BH 530		12.5 m O.D.	NS 8156 9608
0 - 123	cms	Carse.	
123 - 165	cms	Peat.	
165 +	cms	Coarse, brown sand and small gravel.	
BH 531		12.2 m O.D.	NS 8157 9608
0 - 126	cms	Carse.	
126 - 197	cms	Peat.	
197 +	cms	Coarse, brown sand on rock or big gravel.	
BH 532		12.2 m O.D.	NS 8158 9608
0 - 186	cms	Carse.	
186 - 235	cms	Peat.	
235 +	cms	Rock or very big gravel.	
BH 533		12.2 m O.D.	NS 8159 9607
0 - 187	cms	Carse.	
187 - 257	cms	Peat.	
257 +	cms	Coarse sand and gravel.	
BH 534		12.1 m O.D.	NS 8161 9607
0 - 216	cms	Carse.	
216 - 281	cms	Peat.	
281 +	cms	Rock or big gravel.	
BH 535		11.8 m O.D.	NS 8164 9606
0 - 194	cms	Carse.	
194 - 268	cms	Peat. Mixed with clay in top 10-15 cms.	
268 +	cms	Very coarse, pink, silty sand.	

BH 536		12.4 m O.D.	NS 8154 9601
0 - 159 cms	Carse.		
159 - 191 cms	Peat. Mixed with clay in top 10 cms.		
191 + cms	Coarse, brown sand.		
BH 537		12.0 m O.D.	NS 8155 9601
0 - 192 cms	Carse.		
192 - 201 cms	Peat.		
201 + cms	Tough, brown sand.		
BH 538		11.9 m O.D.	NS 8158 9599
0 - 222 cms	Carse.		
222 - 230 cms	Peat.		
230 - 241 cms	Grey/green, silty clay.		
241 + cms	Coarse, pink, silty sand.		
BH 539		12.0 m O.D.	NS 8159 9599
0 - 216 cms	Carse.		
216 - 225 cms	Peat.		
225 + cms	Coarse, grey sand.		
BH 540		12.1 m O.D.	NS 8159 9603
0 - 235 cms	Carse.		
235 - 256 cms	Peat.		
256 + cms	Coarse, grey sand.		
BH 541		12.1 m O.D.	NS 8158 9602
0 - 249 cms	Carse.		
249 - 266 cms	Peat.		
266 + cms	Grey/brown sand.		
BH 542		7.6 m O.D.	NS 8463 9518
0 - 290+ cms	Tough, red/brown sand.		
BH 543		7.2 m O.D.	NS 8461 9518
0 - 224 cms	Carse. Tough and very sandy in top 30-40 cms. Softer near base.		
224 + cms	Gravel.		
BH 544		6.6 m O.D.	NS 8457 9519
0 - 167 cms	Carse.		
167 + cms	Coarse, grey sand and small gravel.		
BH 545		7.2 m O.D.	NS 8454 9519
0 - 244 cms	Carse.		
244 + cms	Coarse, grey/pink sand and small gravel.		
BH 546		8.0 m O.D.	NS 8449 9519
0 - 286 cms	Carse.		
286 + cms	Rock or big gravel with thin layer of pink/grey sand on top.		

BH 547		8.0 m O.D.	NS 8445 9519
0 - 311 cms	Carse. Very dark and sandy near base.		
311 + cms	Black sand and small gravel.		
BH 548		6.8 m O.D.	NS 8459 9519
0 - 100+ cms	Orange/red sand.		
BH 549		7.8 m O.D.	NS 8441 9519
0 - 362 cms	Carse. Dark and sandy near base.		
362 + cms	Coarse sand and gravel.		
BH 550		8.3 m O.D.	NS 8428 9518
0 - ? cms	Carse.		
? - 243 cms	Peat.		
243 - 280 cms	Grey, silty clay.		
280 + cms	Quite coarse, grey, silty sand.		
BH 551		8.0 m O.D.	NS 8432 9518
0 - 194 cms	Carse.		
194 - 215 cms	Peat.		
215 - 244 cms	Grey, silty clay.		
244 + cms	Grey, silty sand.		
BH 552		7.7 m O.D.	NS 8435 9518
0 - 299 cms	Carse. Very black with some shells near base.		
299 + cms	Pink/grey, silty sand.		
BH 553		7.7 m O.D.	NS 8419 9518
0 - 164 cms	Carse.		
164 - 180 cms	Coarse, brown sand.		
180 - 325 cms	Carse-clay with sandy bands. Very dark near base.		
325 + cms	Light grey, silty sand.		
BH 554		8.0 m O.D.	NS 8422 9518
0 - 220 cms	Carse.		
220 - 223 cms	Peat.		
223 - 246 cms	Grey, silty sand.		
246 + cms	Grey/pink, silty sand.		
BH 555		8.8 m O.D.	NS 8422 9527
0 - 440+ cms	Carse. Contains bands of sand that increase in frequency with depth.		
BH 556		8.8 m O.D.	NS 8431 9527
0 - 217 cms	Carse.		
217 - 241 cms	Peat.		
241 + cms	Grey/green, silty clay.		
BH 557		7.2 m O.D.	NS 8404 9515
0 - 450 cms	Carse. Tough and sandy with depth.		
450 + cms	Coarse sand and gravel.		
BH 558		Not Levelled	NS 8403 9539
0 - 462+ cms	Carse with sand and shell beds from c.320 cms.		

BH 559	8.5 m O.D.	NS 8439 9527
0 - 348 cms	Carse. Coarser with depth.	
348 + cms	Coarse sand and gravel.	
BH 560	8.4 m O.D.	NS 8435 9527
0 - 336+ cms	Carse. Increasingly tough with depth.	
BH 561	8.4 m O.D.	NS 8439 9535
0 - 325+ cms	Carse. Dark, sandy and tough.	
BH 562	8.8 m O.D.	NS 8431 9535
0 - 300+ cms	Carse. Darker and sandier with depth.	
BH 563	7.1 m O.D.	NS 8445 9535
0 - 95 cms	Red/brown sand.	
95 + cms	Coarse sand and gravel.	
BH 564	8.2 m O.D.	NS 8443 9535
0 - 248 cms	Carse. Coarser with depth.	
248 + cms	Dark grey/black, coarse sand and small gravel.	
BH 565	6.6 m O.D.	NS 8445 9541
0 - 102 cms	Carse.	
102 + cms	Very coarse sand.	
BH 566	Not Levelled	NS 8443 9552
0 - 207 cms	Very tough carse.	
207 + cms	Gravel and coarse sand.	
BH 567	Not Levelled	NS 8439 9551
0 - 233+ cms	Very coarse, red/brown sand.	
BH 568	Not Levelled	NS 8435 9551
0 - 200+ cms	Coarse but soft, red/brown sand.	
BH 569	11.2 m O.D.	NS 8424 9672
0 - 161 cms	Carse.	
161 - 175 cms	Clay/peat mixture.	
175 + cms	Pink, silty sand and clay.	
BH 570	11.3 m O.D.	NS 8425 9667
0 - 197 cms	Carse.	
197 + cms	Pink, silty sand. Some peat mixed in top 4-5 cms.	
BH 571	11.5 m O.D.	NS 8428 9657
0 - 324 cms	Very tough carse.	
324 - 333 cms	Peat.	
333 + cms	Grey/pink, silty sand.	
BH 572	11.4 m O.D.	NS 8427 9661
0 - 361 cms	Carse.	
361 + cms	Pink/brown sand.	

BH 573	11.4 m O.D.	NS 8425 9665
0 - 267 cms	Carse.	
267 - 271 cms	Clay/peat mixture.	
271 - 284 cms	Grey clay.	
284 + cms	Pink, silty sand.	

BH 574	11.3 m O.D.	NS 8431 9648
0 - 363 cms	Very tough carse.	
363 + cms	Tough, pink, silty sand.	

BH 575	11.3 m O.D.	NS 8431 9646
0 - 357 cms	Very tough carse.	
357 + cms	Pink, silty sand with 2-3 cms of grey, silty sand on top.	

BH 576	11.4 m O.D.	NS 8429 9652
0 - 302 cms	Extremely tough carse.	
302 + cms	Grey/pink, silty sand with 2-3 cms of mixed clay and peat on top.	

BH 577	11.5 m O.D.	NS 8419 9639
0 - 398 cms	Very tough carse.	
398 - 414 cms	Peat.	
414 - 430 cms	Grey, silty clay.	
430 + cms	Pink, silty sand.	

BH 578	8.7 m O.D.	NS 8407 9634
0 - 99 cms	Soft carse.	
99 - 108 cms	Peat.	
108 - 126 cms	Grey, silty sand.	
126 + cms	Pink, silty sand.	

BH 579	8.6 m O.D.	NS 8409 9626
0 - 115 cms	Carse. Shells at base.	
115 - 131 cms	Grey, silty sand.	
131 + cms	Pink, silty sand.	

BH 580	8.8 m O.D.	NS 8414 9618
0 - 122 cms	Carse.	
122 - 144 cms	Peat.	
144 + cms	Grey, silty sand.	

BH 581	8.4 m O.D.	NS 8422 9608
0 - 131 cms	Carse.	
131 - 148 cms	Peat.	
148 + cms	Grey, silty sand.	

BH 582	12.2 m O.D.	NS 8214 9688
0 - 65 cms	Slightly clayey peat.	
65 - 119 cms	Carse-clay.	
119 - 136 cms	Peat.	
136 + cms	Gravel.	

BH 583		12.4 m O.D.	NS 8215 9685
0 - 189	cms	Carse.	
189 - 237	cms	Peat.	
237 +	cms	Pink, silty sand. Slightly grey in top 2-3 cms.	

BH 584		12.4 m O.D.	NS 8214 9687
0 - 145	cms	Carse.	
145 - 201	cms	Peat.	
201 +	cms	Pink, silty sand.	

BH 585		11.9 m O.D.	NS 8222 9688
0 - ?	cms	Carse. Mixed with gravel from adjacent fan.	
? - 121	cms	Peat.	
121 +	cms	Pink, silty sand. Slightly grey in top few cms.	

BH 586		11.6 m O.D.	NS 8222 9685
0 - ?	cms	Carse. Mixed with peat in top 40 cms.	
? - 146	cms	Peat.	
146 +	cms	Pink, silty sand. Slightly grey at top.	

BH 587		11.5 m O.D.	NS 8232 9683
0 - 121	cms	Carse.	
121 - 152	cms	Peat. Mixed with clay in top 10 cms.	
152 +	cms	Coarse, grey/brown sand.	

BH 588		12.1 m O.D.	NS 8232 9685
0 - 40	cms	Carse/gravel mixture.	
40 +	cms	Gravel.	

BH 589		11.6 m O.D.	NS 8232 9684
0 - 71	cms	Carse.	
71 +	cms	Gravel.	

BH 590		11.3 m O.D.	NS 8232 9682
0 - 154	cms	Carse.	
154 - 189	cms	Peat.	
189 +	cms	Coarse, pink/brown sand.	

BH 591		11.6 m O.D.	NS 8237 9683
0 - ?	cms	Carse.	
? - 187	cms	Peat.	
187 +	cms	Grey/brown, coarse, silty sand, becoming pink with depth.	

BH 592		11.3 m O.D.	NS 8236 9684
0 - 117	cms	Carse.	
117 - 154	cms	Peat.	
154 - 172	cms	Grey/pink, silty sand.	
172 +	cms	Pink, silty sand.	

BH 593		12.4 m O.D.	NS 8249 9683
0 - 256	cms	Carse.	
256 - 275	cms	Peat.	
275 - 302	cms	Grey, silty clay.	
302 +	cms	Pink clay and sand.	

BH 594	12.1 m O.D.	NS 8248 9682
0 - 184 cms	Carse.	
184 - 217 cms	Peat.	
217 + cms	Pink, silty sand. Grey in top few cms.	
BH 595	12.0 m O.D.	NS 8261 9686
0 - 120 cms	Carse.	
120 - 186 cms	Peat.	
186 + cms	Pink, silty sand.	
BH 596	12.6 m O.D.	NS 6701 9924
0 - 72 cms	Sandy carse.	
72 + cms	Coarse, pink sand.	
BH 597	12.8 m O.D.	NS 6702 9921
0 - 97+ cms	Very tough, pink carse. From c.70 cms it contains pink and white sand - possibly rotted sandstone.	
BH 598	12.8 m O.D.	NS 6699 9917
0 - 99+ cms	Very sandy carse. Too tough to penetrate beyond 99 cms.	
BH 599	12.4 m O.D.	NS 6697 9912
0 - 130 cms	Red/brown sand.	
130 + cms	Rock or big gravel.	
BH 600	12.9 m O.D.	NS 6709 9925
0 - 79 cms	Mixed sand and clay. Sand increases in proportion from 79 cms and too tough to penetrate beyond c.93 cms.	
BH 601	13.2 m O.D.	NS 6708 9921
0 - 115 cms	Red/brown sand.	
115 - 201 cms	Grey carse-clay.	
201 + cms	Pink, silty sand.	
BH 602	13.1 m O.D.	NS 6708 9923
0 - 141 cms	Red/brown sand.	
141 - 171 cms	Grey carse-clay.	
171 + cms	Pink, silty sand.	
BH 603	13.3 m O.D.	NS 6717 9925
0 - 101 cms	Red/brown sand with some small gravel. Too tough to penetrate beyond 101 cms.	
BH 604	13.6 m O.D.	NS 6717 9923
0 - 117 cms	Red/brown sand.	
117 - 218 cms	Carse-clay.	
218 + cms	Several cms of pink, silty sand resting upon rotted grey sandstone.	
BH 605	14.4 m O.D.	NS 6727 9925
0 - 126 cms	Red/brown sand.	
126 + cms	Grey/white, silty sand with small gravel.	

BH 606		13.8 m O.D.	NS 6725 9923
0 - 127	cms	Brown, clayey sand.	
127 - 211	cms	Blue/grey carse-clay.	
211 +	cms	Very coarse, pink, silty sand.	
BH 607		13.7 m O.D.	NS 7627 9925
0 - 161	cms	Red/brown sand. More clayey with depth.	
161 +	cms	Coarse, pink, silty sand.	
BH 608		13.5 m O.D.	NS 6726 9919
0 - 60	cms	Red/brown sand. Boring stopped at c.60 cms by solid sandstone or gravel.	
BH 609		13.7 m O.D.	NS 6727 9921
0 - 94	cms	Coarse, red/brown sand.	
94 +	cms	Coarse gravel.	
BH 610		13.6 m O.D.	NS 6729 9919
0 - 92	cms	Red/brown sand. Some clay near base.	
92 +	cms	Gravel.	
BH 611		13.6 m O.D.	NS 6727 9918
0 - 138	cms	Red/brown sand, giving way to coarse, brown/pink sand and gravel.	
BH 612		13.1 m O.D.	NS 6744 9874
0 - 256	cms	Carse with some sandy bands.	
256 +	cms	Pink, silty sand.	
BH 613		13.0 m O.D.	NS 6754 9871
0 - 259	cms	Carse.	
259 +	cms	Pink, silty sand.	
BH 614		13.6 m O.D.	NS 6756 9875
0 - 98	cms	Carse, with some sand.	
98 +	cms	Coarse, grey/brown sand.	
BH 615		13.3 m O.D.	NS 6755 9873
0 - 253	cms	Carse.	
253 +	cms	Pink, silty sand.	
BH 616		13.4 m O.D.	NS 6754 9874
0 - 219	cms	Carse.	
219 +	cms	Coarse, pink sand and small gravel.	
BH 617		13.1 m O.D.	NS 6749 9864
0 - 367	cms	Carse.	
367 +	cms	Pink, silty sand.	
BH 618		13.2 m O.D.	NS 6751 9868
0 - 311	cms	Carse.	
311 +	cms	Pink, silty sand.	
BH 619		13.4 m O.D.	NS 6749 9869
0 - 335	cms	Carse.	
335 +	cms	Pink, silty sand.	

BH 620		13.0 m O.D.	NS 6744 9856
0 - 448 cms	Carse.		
448 + cms	Coarse, pink sand.		
BH 621		13.2 m O.D.	NS 6742 9857
0 - 489 cms	Carse.		
489 + cms	Red sand. Includes some shell fragments.		
BH 622		12.9 m O.D.	NS 6741 9849
0 - 501 cms	Carse. Shelly near base.		
501 - 507 cms	Red, shelly sand.		
507 + cms	Light grey, tough sand.		
BH 623		12.9 m O.D.	NS 6738 9845
0 - 382 cms	Carse.		
382 + cms	Tough, grey, silty sand.		
BH 624		12.8 m O.D.	NS 6742 9857
0 - 487 cms	Carse. Mixed with red, shelly sand near base.		
487 + cms	Grey, silty sand.		
BH 625		12.7 m O.D.	NS 6735 9875
0 - 107 cms	Carse.		
107 + cms	Pink, silty sand with some coarse, pink sand in top few cms.		
BH 626		11.8 m O.D.	NS 6722 9893
0 - 138 cms	Carse.		
138 + cms	Coarse, pink, silty sand and small gravel.		
BH 627		12.6 m O.D.	NS 6719 9893
0 - 371 cms	Carse.		
371 + cms	Pink, silty sand.		
BH 628		13.4 m O.D.	NS 6714 9879
0 - 462 cms	Carse. Quite sandy at top.		
462 + cms	Grey, silty sand.		
BH 629		13.6 m O.D.	NS 6718 9876
0 - 424 cms	Carse.		
424 + cms	Pink, silty sand.		
BH 630		16.1 m O.D.	NS 6284 9844
0 - 253 cms	Peat.		
253 - 872+ cms	Carse. Clay at top, but giving way to sandy clay and sand with depth.		
BH 631		13.2 m O.D.	NS 6279 9841
0 - 329 cms	Peat.		
329 + cms	Carse-clay.		

Boring stopped at 776 cms where grey, silty sand was present. Exact details of stratigraphy not known, but top of buried peat thought to be at c.400-420 cms.

BH 632	16.3 m O.D.	NS 6292 9848
0 - 210 cms	Peat.	
210 - 629 cms	Carse-clay.	
629 - 654 cms	Peat.	
654 + cms	Grey, silty sand.	

BH 633	13.5 m O.D.	NS 6289 9847
0 - 65 cms	Peat.	
65 - 626 cms	Carse-clay. Coarser with depth.	
626 + cms	Coarse, grey/brown sand, too tough for further boring.	

BH 634	14.1 m O.D.	NS 6372 0048
0 - 112 cms	Red sand, with some clay.	
112 - 125 cms	Peat.	
125 + cms	Pink, silty sand, grading to sand at c.140 cms.	

BH 635	14.0 m O.D.	NS 6371 0047
0 - ? cms	Carse.	
? - 116 cms	Peat.	
116 + cms	Pink, silty sand, grading to pink sand.	

BH 636	13.5 m O.D.	NS 6368 0044
0 - 85 cms	Carse.	
85 - 87 cms	Peat.	
87 - 111 cms	Pink, silty sand, grading to pink sand.	
111 + cms	Coarse, red sand and gravel.	

BH 637	13.8 m O.D.	NS 6368 0041
0 - 157 cms	Carse.	
157 - 168 cms	Peat.	
168 - 187 cms	Grey, silty clay.	
187 + cms	Pink sand.	

BH 638	13.5 m O.D.	NS 6372 0039
0 - 85 cms	Carse.	
85 - 97 cms	Clay/peat mixture.	
97 - 108 cms	Grey/pink, silty sand.	
108 + cms	Coarse, red sand.	

BH 639	14.1 m O.D.	NS 6436 0014
0 - 81 cms	Carse.	
81 - 87 cms	Peat.	
87 + cms	Grey/brown sand.	

BH 640	13.9 m O.D.	NS 6436 0013
0 - ? cms	Carse.	
? - 131 cms	Peat.	
131 - 140 cms	Grey, silty sand.	
140 + cms	Pink, silty sand.	

BH 641	13.7 m O.D.	NS 6436 0008
0 - 183 cms	Carse.	
183 + cms	Pink, silty sand.	

BH 642 | 13.8 m O.D. | NS 6436 0011

0 - 117 cms Carse.
117 - 135 cms Peat.
135 - 141 cms Grey clay and sand.
141 + cms Pink, silty sand.

BH 643 | 13.0 m O.D. | NS 6438 9999

0 - 165 cms Carse. Coarser with depth.
165 - 211 cms Coarse (but soft) grey/brown sand.
211 + cms Coarse, grey sand including some clay but very tough.

BH 644 | 12.2 m O.D. | NS 6439 9997

0 - 269 cms Carse. Darker with depth.
269 + cms Fine, grey/brown sand.

BH 645 | 13.6 m O.D. | NS 6432 9992

0 - 491 cms Carse. Shells at c.350 cms.
491 + cms Rock (or big gravel).

BH 646 | 13.8 m O.D. | NS 6433 9988

0 - 575 cms Carse.
575 + cms Very coarse, black sand.

BH 647 | 14.0 m O.D. | NS 6434 9984

0 - 550+ cms Carse.
Dark blue/black carse-clay still present at 550 cms.

BH 648 | 13.0 m O.D. | NS 6414 9994

0 - 447 cms Carse.
447 + cms Rock (or big gravel).

BH 649 | 13.7 m O.D. | NS 6415 9985

0 - 313 cms Carse.
313 - c.420 cms Peat, mixed with clay in top 5-6 cms. Peat still present at 358 cms where it is too tough to penetrate. Comparison with other holes suggests that grey, silty sand is probably present at c.420 cms.
c.420 + cms Grey, silty sand.

BH 650 | 13.6 m O.D. | NS 6415 9989

0 - 532 cms Carse.
532 + cms Coarse sand and small gravel.

BH 651 | 13.4 m O.D. | NS 6383 9989

0 - 235 cms Carse.
235 - 341 cms Peat.
341 + cms Grey, silty sand.

BH 652 | 13.5 m O.D. | NS 6388 9989

0 - 478 cms Carse.
478 + cms Tough (but fine) grey sand.

BH 653		11.6 m O.D.	NS 6381 9991
0 - 85 cms	Peat.		
85 - 284 cms	Grey, silty sand. Variable toughness. Extremely micaceous.		
284 + cms	Grey/pink sand.		
BH 654		13.8 m O.D.	NS 6375 9993
0 - 272 cms	Carse.		
272 + cms	Peat. Too tough to penetrate, but taken as indicative of grey, silty sand present at c.380-400 cms.		
BH 655		13.7 m O.D.	NS 6368 9997
0 - 285 cms	Carse.		
285 + cms	Peat.		
Grey, silty sand	present probably at 400+ cms.		
BH 656		Not Levelled	NS 6369 9998
0 - 223 cms	Carse.		
223 + cms	Peat. Too tough to penetrate.		
BH 657		14.9 m O.D.	NS 6273 0064
0 - 211 cms	Carse, mixed with peat in top 80 cms.		
211 + cms	Grey/brown, silty sand. Thin pink clay at junction.		
BH 658		14.6 m O.D.	NS 6274 0061
0 - 178 cms	Carse.		
178 + cms	Tough, brown, silty sand.		
BH 659		14.5 m O.D.	NS 6275 0057
0 - 174 cms	Carse.		
174 + cms	Brown, silty sand.		
BH 660		14.2 m O.D.	NS 6279 0049
0 - 251 cms	Carse.		
251 - 275 cms	Peat.		
275 + cms	Grey, silty sand.		
BH 661		14.4 m O.D.	NS 6277 0055
0 - 232 cms	Carse.		
232 + cms	Brown, silty sand.		
BH 662		14.5 m O.D.	NS 6276 0053
0 - 276 cms	Carse.		
276 + cms	Fine, brown sand.		
BH 663		14.4 m O.D.	NS 6278 0052
0 - 334 cms	Carse. Becoming blue/black with depth.		
334 + cms	Pink/brown, fine sand.		
BH 664		14.1 m O.D.	NS 6283 0042
0 - 310 cms	Carse.		
310 - 351 cms	Peat.		
351 + cms	Brown sand, mixed with peat.		

BH 665		14.2 m O.D.	NS 6285 0039
0 - 298 cms	Carse.		
298 - 346 cms	Peat.		
346 + cms	Grey, silty sand.		
BH 666		14.9 m O.D.	NS 6152 9944
0 - 183 cms	Peat.		
183 + cms	Gravel.		
BH 667		15.4 m O.D.	NS 6158 9952
0 - 643 cms	Peat and carse.		
643 - 651 cms	Peat.		
651 - 721 cms	Grey, silty sand.		
721 + cms	Gravel.		
BH 668		15.8 m O.D.	NS 6161 9959
0 - 800 cms	Peat and carse.		
800 + cms	Carse still present but penetration difficult.		
BH 669		14.0 m O.D.	NS 6167 9965
0 - 713 cms	Peat and carse.		
713 + cms	Carse still present but very tough.		
BH 670		14.3 m O.D.	NS 7166 9851
0 - ? cms	Carse mixed with peat.		
? - 327 cms	Peat.		
327 + cms	Coarse, grey/brown sand.		
BH 671		13.6 m O.D.	NS 7163 9848
0 - 217 cms	Carse.		
217 - 311 cms	Peat.		
311 + cms	Very tough, grey, silty sand.		
BH 672		13.9 m O.D.	NS 7165 9853
0 - 80 cms	Peat.		
80 - 321 cms	Carse.		
321 + cms	Grey, silty sand.		
BH 673		13.6 m O.D.	NS 7174 9854
0 - 45 cms	Peat.		
45 - ? cms	Carse.		
? - 299 cms	Peat.		
299 + cms	Grey, silty sand.		
BH 674		13.9 m O.D.	NS 7183 9855
0 - 288 cms	Carse. Mixed with peat at top.		
288 - 307 cms	Peat.		
307 + cms	Grey, silty sand.		
BH 675		14.5 m O.D.	NS 7192 9856
0 - 363 cms	Carse.		
363 - 375 cms	Peat.		
375 + cms	Grey, silty sand.		

BH 676	15.9 m O.D.	NS 7199 9858
0 - 100 cms	Sandy clay.	
100 - 196 cms	Clay.	
196 - 502 cms	Sandy clay.	
502 - 517 cms	Peat.	
517 + cms	Grey, silty sand.	
BH 677	13.2 m O.D.	NS 7237 9845
0 - 70 cms	Peat.	
70 - ? cms	Carse-clay.	
? - 353 cms	Peat.	
353 + cms	Tough, grey, silty sand.	
BH 678	13.2 m O.D.	NS 7245 9839
0 - 75 cms	Peat.	
75 - 343 cms	Carse.	
343 + cms	Grey/green, silty sand.	
BH 679	13.3 m O.D.	NS 7252 9835
0 - 60 cms	Peat.	
60 - 362 cms	Carse.	
362 + cms	Coarse sand and small gravel.	
BH 680	13.1 m O.D.	NS 7249 9837
0 - 45 cms	Peat.	
45 - 321 cms	Carse.	
321 - 326 cms	Peat.	
326 - 338 cms	Transition zone.	
338 - 361 cms	Grey, silty sand.	
361 + cms	Coarse, grey sand and small gravel.	
BH 681	11.9 m O.D.	NS 7271 9693
0 - 541 cms	Carse. Sandier with depth.	
541 - 563 cms	Sand with shell fragments.	
563 + cms	Medium and big gravel.	
BH 682	11.7 m O.D.	NS 7273 9701
0 - 486 cms	Very tough carse. Sandier with depth.	
486 - 518 cms	Sand and clay.	
518 + cms	Big gravel.	
BH 683	11.8 m O.D.	NS 7277 9709
0 - c.470 cms	Carse.	
470 - 509 cms	Very sandy clay with shells.	
509 + cms	Gravel.	
BH 684	11.7 m O.D.	NS 7281 9717
0 - 467 cms	Carse, increasingly sandy with depth.	
467 + cms	Medium to big gravel.	
BH 685	11.9 m O.D.	NS 7284 9728
0 - 429 cms	Carse.	
429 + cms	Tough, grey sand with shells on top.	

BH 686		11.9 m O.D.	NS 7285 9735
0 - 370	cms	Carse. Tough near base.	
370 - 408	cms	Grey, slightly green sand.	
408 +	cms	Gravel.	
BH 687		11.8 m O.D.	NS 7278 9738
0 - 388	cms	Carse.	
388 - 409	cms	Grey, slightly green sand.	
409 +	cms	Gravel.	
BH 688		11.8 m O.D.	NS 7274 9729
0 - 425	cms	Carse.	
425 - 437	cms	Coarse sand. Mainly grey but with green and pink streaks.	
437 +	cms	Gravel.	
BH 689		11.5 m O.D.	NS 7047 9832
0 - 44	cms	Clay.	
44 - 92	cms	Peat.	
92 +	cms	Grey/green, silty sand. Slightly pink with depth.	
BH 690		11.7 m O.D.	NS 7049 9829
0 - 57	cms	Clay.	
57 - 119	cms	Peat.	
119 +	cms	Grey, silty sand.	
BH 691		11.9 m O.D.	NS 7065 9843
0 - 39	cms	Sandy carse.	
39 - 47	cms	Peat.	
47 +	cms	Pink, sandy clay. Becoming gritty with depth.	
BH 692		11.3 m O.D.	NS 7067 9841
0 - 37	cms	Carse.	
37 - 53	cms	Peat.	
53 +	cms	Very tough, grey, silty sand.	
BH 693		11.4 m O.D.	NS 7066 9842
0 - 42	cms	Carse.	
42 - 60	cms	Peat.	
60 - 93	cms	Grey, silty sand.	
93 +	cms	Pink, silty sand.	
BH 694		12.9 m O.D.	NS 7083 9854
0 - 60	cms	Sandy carse.	
60 +	cms	Tough sand.	
BH 695		12.1 m O.D.	NS 7085 9849
0 - 43	cms	Sandy carse.	
43 - 143	cms	Peat.	
143 - 166	cms	Grey, silty sand.	
166 +	cms	Pink, silty sand.	

BH 696 11.9 m O.D. NS 7084 9851

0 - 45 cms	Carse.
45 - 97 cms	Peat.
97 - 105 cms	Grey, silty sand.
105 + cms	Pink, silty sand. Coarser with depth.

BH 697 14.2 m O.D. NS 7096 9869

0 - 63 cms	Sandy carse.
63 - 88 cms	Clay.
88 - 101 cms	Peat.
101 + cms	Coarse, orange/brown sand.

BH 698 14.3 m O.D. NS 7027 9824

0 - 54 cms	Sandy clay.
54 - 62 cms	Peat.
62 - 112 cms	Clay.
112 + cms	Red/brown sand.

BH 699 13.8 m O.D. NS 7029 9822

0 - 254 cms	Carse. Very sandy near base.
254 - 335 cms	Peat.
335 + cms	Grey/green, silty sand.

BH 700 14.0 m O.D. NS 7028 9823

0 - 177 cms	Carse.
177 - 264 cms	Pink/grey sand.
264 - 320 cms	Peat.
320 + cms	Gritty, red sand.

BH 701 12.9 m O.D. NS 7021 9812

0 - 267 cms	Carse.
267 - 348 cms	Woody peat.
348 + cms	Grey, silty sand.

BH 702 12.4 m O.D. NS 6845 9795

0 - 489 cms	Carse.
489 + cms	Tough, grey sand.

BH 703 12.8 m O.D. NS 6853 9769

0 - 344 cms	Carse.
344 + cms	Tough, grey, shelly sand.

BH 704 12.9 m O.D. NS 6864 9802

0 - 169 cms	Carse.
169 + cms	Gravel.

BH 705 12.6 m O.D. NS 7003 9804

0 - 338 cms	Carse.
338 - 409 cms	Peat.
409 + cms	Grey, silty sand. Coarser with depth.

BH 706 13.5 m O.D. NS 6987 9807

0 - 44 cms	Carse.
44 + cms	Gravel.

BH 707		13.5 m O.D.	NS 6987 9805
0 - 369 cms	Carse.		
369 - 462 cms	Peat. Tree at top.		
462 - 496 cms	Grey, silty sand. Slightly coarser with depth.		
496 + cms	Pink, silty sand.		
BH 708		14.4 m O.D.	NS 6641 9953
0 - 74 cms	Carse. Slightly peaty near base.		
74 + cms	Red/brown sand.		
BH 709		13.9 m O.D.	NS 6639 9947
0 - 42 cms	Carse.		
42 + cms	Coarse, red/brown sand.		
BH 710		13.8 m O.D.	NS 6639 9944
0 - 64 cms	Carse. Pinkish in colour.		
64 + cms	Tough, pink/purple sand.		
BH 711		13.5 m O.D.	NS 6638 9938
0 - 68 cms	Carse.		
68 - 73 cms	Coarse, pink/purple sand.		
73 + cms	Rock.		
BH 712		13.8 m O.D.	NS 6649 9934
0 - 92 cms	Carse.		
92 + cms	Pink/purple sand.		
BH 713		13.8 m O.D.	NS 6651 9939
0 - 63 cms	Carse.		
63 + cms	Coarse, red/brown or pink sand.		
BH 714		13.5 m O.D.	NS 6662 9934
0 - 72 cms	Carse.		
72 + cms	Coarse, red/pink sand.		
BH 715		13.7 m O.D.	NS 6662 9939
0 - 63 cms	Carse.		
63 + cms	Coarse, pink sand.		
BH 716		14.3 m O.D.	NS 6622 9958
0 - 79 cms	Peat and carse.		
79 + cms	Coarse, grey/brown sand.		
BH 717		13.9 m O.D.	NS 6623 9952
0 - 79 cms	Carse.		
79 + cms	Coarse, purple/pink sand.		
BH 718		14.6 m O.D.	NS 6613 9969
0 - 74 cms	Carse.		
74 + cms	Coarse, purple/pink sand.		
BH 719		14.0 m O.D.	NS 6614 9957
0 - 91 cms	Carse.		
91 + cms	Rock or gravel.		

BH 720		14.2 m O.D.	NS 6587 9959
0 - 242 cms	Carse.		
242 + cms	Pink, silty sand with some peat on top.		
BH 721		13.9 m O.D.	NS 6585 9954
0 - 364 cms	Carse. Very dark near base.		
364 + cms	Rock.		
BH 722		9.9 m O.D.	NS 7529 9689
0 - 588 cms	Carse. Sandy near base.		
588 + cms	Gravel and coarse, grey sand.		
BH 723		10.0 m O.D.	NS 7511 9675
0 - 564+ cms	Carse. Increasingly tough and sandy near base.		
BH 724		11.2 m O.D.	NS 7499 9665
0 - 668+ cms	Carse. Peaty on top. Very tough. Quite coarse and sandy near base.		
BH 725		9.8 m O.D.	NS 7497 9651
0 - 563+ cms	Carse. Peaty at top. Increasingly tough with depth.		
BH 726		10.5 m O.D.	NS 7513 9678
0 - 622+ cms	Carse. Very tough and sandy at base.		

* * * * * * *

Boreholes noted in the text with reference letters DES are listed in Smith, D.E. 1965, Late and postglacial changes of shoreline on the north side of the Forth valley and estuary.

Those with reference letters JBS are from unpublished records of J.B. Sissons.

APPENDIX B

HEAVY MINERAL ANALYSIS

High Buried Beach sample

NN 6529 0010

Garnet	62
Zircon	54
Chlorite	8
Hornblende	7
Tourmaline	2

Total count: 133 mineral grains.

Low Buried Beach sample

NS 7113 9778

Chlorite	89
Biotite	51
Hornblende	4
Garnet	3
Augite	3

Total count: 150 mineral grains.

Main Buried Beach sample

NS 8194 9591

Garnet	55
Zircon	37
Chlorite	22
Hornblende	16
Augite	6
Enstatite	5
Tourmaline	5
Apatite	2
Hypersthene	2

Total count: 150 mineral grains.

Carse-clay sample

NS 6800 9820

Chlorite	67
Garnet	29
Zircon	27
Hornblende	9
Augite	8
Enstatite	8
Staurolite	3
Epidote	2
Tourmaline	2
Biotite	1

Total count: 156 mineral grains.

APPENDIX C

POLLEN ANALYSIS OF BURIED PEAT AT WESTER KERSE

GRID REFERENCE. NN 6526 0001

STRATIGRAPHICAL INFORMATION. The sample was obtained from the lowest 2.0 cm of peat resting on the surface of the High Buried Beach.

<u>Arboreal Pollen</u>

Pinus	4
Betula	43
Alnus	1
Ulmus	3
Quercus	1
Corylus	21
Salix	22

Total arboreal count 95.

<u>Non-Arboreal Pollen and Spores</u>

<u>Spores</u>

Sphagnum	43
Filicales	6

<u>Pollen</u>

Gramineae	7
Cyperaceae	3
Filipendula	1

Total non-aboreal count 60

APPENDIX D

SUMMARY OF BURIED BEACH REGRESSION ANALYSIS DETAILS

1. HIGH BURIED RAISED BEACH

Menteith-Thornhill

Heights (in metres) 12.8, 11.1, 12.5, 12.5, 13.4, 11.1, 11.6, 11.1, 11.1, 11.2, 10.4, 11.4, 10.3, 13.2, 13.2, 13.1, 13.1

Total 17

$r = -0.3603$

Regression equation: $x = 13.2257 - 0.0197y$

Gradient = 0.197 m/km

Menteith-Thornhill (amended)

Heights (in metres) 12.8, 12.5, 12.5, 11.1, 11.6, 11.1, 11.1, 11.2, 10.4, 11.4, 10.3

Total 11

$r = -0.8788$

Regression equation: $x = 13.9549 - 0.0373y$

Burnbank

Heights (in metres) 10.9, 10.2, 11.1, 10.6, 11.1, 10.7, 10.6, 10.8, 10.7, 10.9

Total 10

$r = +0.078$

(Burnbank continued)

Regression equation: x = 10.3392 + 0.0033y

Gradient = 0.033 m/km

Abbey Craig - Menstrie

Heights (in metres) 9.9, 9.6, 9.1, 8.2, 9.8, 10.1, 9.4, 9.7, 9.6, 10.1, 8.7, 9.4

Total 12

r = -0.094

Regression equation: x = 9.5191 - 0.0056y

Gradient = 0.056 m/km

Abbey Craig - Menstrie (amended)

Heights (in metres) 9.9, 9.6, 9.1, 9.8, 10.1, 9.4, 9.7, 9.6, 10.1, 9.4

Total 10

r = -0.554

Regression equation: x = 9.8269 - 0.0168y

Gradient = 0.168 m/km

2. MAIN BURIED RAISED BEACH

Menteith-Thornhill

Heights (in metres) 12.1, 11.7, 11.3, 11.1, 10.6, 10.1, 10.0, 10.8, 9.5, 9.9, 9.3, 9.0

Total 12

r = -0.9487

Regression equation: x = 11.8398 - 0.0426y

Gradient = 0.426 m/km

Burnbank

Heights (in metres) 9.2, 8.9, 8.5, 9.8, 9.8

Total 5

r = +0.7862

Regression equation: x = 5.5623 + 0.0299y

Gradient = 0.299 m/km

Abbey Craig-Menstrie

Heights (in metres) 7.4, 7.2, 7.3, 7.3, 7.5, 7.0, 7.2, 7.2

Total 8

r = -0.2730

Regression equation: x = 7.3229 - 0.0053y

Gradient = 0.053 m/km

3. LOW BURIED RAISED BEACH

Menteith-Thornhill

Heights (in metres) 8.1, 7.8, 8.0, 8.2, 7.4, 7.4, 8.1

Total 7

r = -0.799

Regression equation: x = 8.4747 - 0.0116y

Gradient = 0.116 m/km

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