Western Forth Valley

D.E. Smith

Highlights

The interest of this area includes an outstanding assemblage of moraine ridges, outwash sediments and a sequence of buried estuarine deposits and peats. These landforms and deposits provide an exceptionally detailed record of the glacial history and sequence of sea-level changes in central Scotland at the end of the Late Devensian and during the early and middle Holocene.

Introduction

At the head of the Forth valley, around the Lake of Menteith (Figure 13.6), a belt of moraine ridges, glaciofluvial deposits and sequences of marine deposits record the advance and decay of a Loch Lomond Readvance glacier, together with related and subsequent changes in relative sea level. This assemblage of landforms and deposits has been studied for over 100 years (Jamieson, 1865; Simpson, 1933; D. E. Smith, 1965, 1968; Newey, 1966; Sissons, 1966, 1972b, 1976e; Sissons and Smith, 1965b; Sissons *et al.,* 1965; Sissons and Brooks, 1971; Brooks, 1972; Gray and Brooks, 1972; Kemp, 1971, 1976). It represents probably the most detailed evidence for readvance, deglaciation and relative sea-level change during the Late Devensian and early Holocene in Scotland. The extensive early literature on the area has been reviewed by Smith (1965).

The main features of this area are particularly well-illustrated at four key sites: these are identified on the accompanying generalized geo-morphological map (Figure 13.6) as site I (Inchie), site II (Easter Garden), site III (West Moss-side) and site IV (Easter Poldar). In the account that follows, the landforms and deposits attributable to glacial advance, retreat and relative sea-level change are summarized before more detailed descriptions and interpretations are given for the key sites.

Description

The Forth valley is a broad lowland running some 40 km eastwards from the edge of the Highlands to the head of the Firth of Forth. The surrounding landscape reflects the varied geology of the area, but the lowland is distinguished by extensive areas of raised estuarine deposits, which occur on both sides of the River Forth throughout its length. These deposits consist of a grey silty clay with occasional lenses of sand, and are known locally as carse clay. They form a remarkably uniform surface, in which local changes of level of more than 1 m are rare. These carselands extend up to 3 km either side of the Forth, and occupy an area in excess of 50 km. A sharp break of slope occurs where they meet the sides of the lowland, which are for the most part mantled in glacial and glaciofluvial deposits.

West of the village of Kippen [NS 650 948], the head of the lowland is occupied by large numbers of glacial and glaciofluvial features, and the carselands are restricted to narrow areas along the Forth and Goodie Water. It is these landforms and deposits which represent the key interest.

Glacial events

The glacial and glaciofluvial landforms and deposits of the Western Forth Valley have long attracted attention, with Jamieson (1865) apparently the. first to have recognized an ice limit. In 1933, Simpson maintained that subsequent to general ice-sheet glaciation, ice had readvanced eastwards into the area, citing as evidence for this a section near Inchie where grey clay with marine shells was overlain by sands and gravels (see below). He called this event the Loch Lomond Readvance. In 1956, Charlesworth supported the view that an important ice limit could be identified here, correlating it with his 'Moraine Glaciation'.

Since 1962, more systematic studies of the glacial and glaciofluvial landforms and deposits of the area have been undertaken (for example, Sissons *et al.,* 1965; Smith, 1965). These studies confirm the evidence of a readvance moraine, and describe the landforms and deposits of the area in some detail. The frontal margin of a major ice limit can be traced in a broad belt of moraine ridges which forms an arc across the valley between Port of Menteith [NN 584 012] and Buchlyvie [NS 575 937]. The northern and southern limbs of this belt (A and B, (Figure 13.6)) are elongate areas each composed of a large number of small ridges, most of which trend across the valley. These areas are dissected by deep channels leading eastward, and in some of these channels there are terraces composed of coarse sands and gravels. The two areas of ridges are thought to be push moraines; the channels, routeways for proglacial meltwaters (Smith, 1965).

The central part of the belt (C, (Figure 13.6)) does not contain such clear evidence. It consists of a broad ridge running parallel to the axis of the valley, with a number of smaller ridges on its surface. The area extends about 1 km east of the ridged areas to the north and south. Exposures show the main ridge to be composed of bedrock (Smith, 1965; Laxton, 1984), whereas the smaller ridges are apparently formed of sands and gravels. Many of the smaller ridges are orientated parallel to the valley axis and to the axis of the main ridge, rather than across it; only a few of them continue the trends of the northern and southern limbs of the belt. Through this area thread a number of sinuous meltwater channels. It is possible that some of the ridges may have been crevasse fillings, and some channel systems may have operated proglacially. Smith (1965) argued that, in view of the fact that this central area extends beyond the ridged areas to the north and south, some of the deposits in it may have been formed earlier than in the latter two areas, perhaps during earlier ice-sheet deglaciation. It seems that the contrast between the central part of the belt and the areas to the north and south reflects the bedrock topography over which the glacier advanced.

The recession of ice from its limit is recorded in a number of glaciofluvial landforms lying west of the moraine belt. Thus, on the hillslopes above Port of Menteith, 'staircases' of kame terraces with associated marginal meltwater channels and, below these, subglacial chutes (D, (Figure 13.6)) record the downwasting of the ice mass which had formed the moraine belt; west of the Lake of Menteith, outwash terraces (E, (Figure 13.6)) probably record the further retreat of the ice mass. Kettle holes in the area west of the moraine belt indicate the wastage of ice detached from the formerly more extensive glacier.

In 1957, Donner concluded from pollen analysis of sites in the general area that the ice limit here belonged to Pollen Zone III of the Jessen-.Godwin system of pollen zonation, or some time between 10,800 and 10,300 BP. This inferred date has subsequently been supported by radiocarbon dating of shells from Simpson's section (Sissons, 1967b) (see below), and the limit (the Menteith Moraine) is correlated with the Loch Lomond Readvance elsewhere in Scotland (Sissons *et al.,* 1973; Sissons, 1974c).

Relative sea-level changes

The study of changes in relative sea level in the area both during and following the Loch Lomond Readvance, has been an increasing focus of interest in recent years. It has long been known that the carse clay is an estuarine deposit, from the many faunal remains found and recorded during a period of over 300 years (Smith, 1965). However, detailed stratigraphical investigations since the mid-1960s (for example, Sissons and Smith, 1965b; Sissons, 1966, 1972b; Smith, 1968; Sissons and Brooks, 1971; Kemp, 1976; D. E. Smith *et al.,* 1978; M. Robinson, unpublished data) have identified a detailed sequence of relative sea-level changes in the area, in which the carse clays are only one element.

Relative sea levels prior to the Loch Lomond Readvance are not well known. Simpson (1933) believed that the altitude of the top of the shelly clay at Inchie, 65 ft (19.8 m) OD, reflected contemporary relative sea level, but this is now not thought likely in view of the possibility that the sediments may have been disturbed by the readvancing ice. Francis *et al.* (1970) and Laxton (1984) have suggested that certain terraces underlain by thin beds of stratified sands on the valley slopes to the east of the Menteith Moraine were formed during ice-sheet retreat, when sea level was between 18 m and 40 m OD. This interpretation is in contrast to that of Sissons and Smith (1965a) who implied that by the time the ice-sheet had retreated to the Western Forth Valley, relative sea level had fallen to a low level.

During the readvance, relative sea level is thought to have been low. The outwash terraces which lead from the channels in the moraine belt descend to at least 8.8 m OD (Sissons, 1966), and the large outwash fan related to the contemporaneous Teith glacier descends to 6 m OD (Smith *et al.,* 1978; Laxton and Ross, 1983). Subsequently, however, relative sea level rose and three marine terraces, now buried beneath later deposits, were formed in the area of the moraine belt (Sissons, 1966). The highest of these reaches 11.9 m to 12.2 m OD at its inland margin, and has been called the High Buried Beach. It has not been found within the morainic arc, and is considered to have formed while ice stood at the moraine. On this basis, a date of between 10,500 and 10,100 BP has been suggested by Sissons (1966, 1983a) for this shoreline.

The lower terraces (the Main and Low Buried Beaches) are found within the morainic arc and were formed after the ice had withdrawn from the vicinity. They reach, respectively, 11.5 m and 8.0 m OD. Overlying these two lower terraces is a buried peat; detailed study shows that it began accumulating as the sea withdrew from the terraces (Newey, 1966). Radiocarbon dates and pollen analyses from the base of the peat give ages of around 9600 BP for the Main Buried Beach and around 8700 BP for the Low Buried Beach (Sissons, 1966, 1983a; Sissons and Brooks, 1971). From the form of the three buried beaches, Sissons concluded that each had resulted from a brief transgression.

After falling to an unknown level, reached at possibly 8500 BP, relative sea level again rose, and the carse clays began to accumulate in the now expanded Forth estuary. This transgression is known as the Main Postglacial Transgression (Sissons, 1974c). As the sea rose, silts and clays were deposited on the peat on the surface of the buried beaches. In two areas, however, peat continued to accumulate faster than the rise in relative sea level. These areas lie on either side of the morainic arc, at East and West Flanders Moss (Figure 13.6). There, islands of peat formed (Sissons and Smith, 1965b) (see below). During this period, a North Sea storm surge (Smith *et al.,* 1985a; Haggart, 1988b) or more probably a tsunami (Dawson *et al.,* 1988; Long *et al.,* 1989a) penetrated the Western Forth Valley and a layer of fine sand accumulated up to at least 11.2 m OD in the estuarine sediments and surrounding peat at approximately 7000 BP (Sissons and Smith, 1965b; Smith *et al.,* 1985a). As the Main Postglacial Transgression continued, carse days were deposited up to about 15 m OD (D. E. Smith, 1968). The consistent altitude of the inner margin of the carse clays in this area is taken to mark a shoreline, the Main Postglacial Shoreline (Sissons, 1974c). Subsequently, relative sea level fell and peat began to accumulate on the carse clay surface, and the peat islands expanded over the adjacent clays. A radiocarbon date from a site within the morainic arc and south of the Forth gave the age of peat immediately beneath the carse clay at 7480 ± 125 BP, and another in the same area for peat resting upon the carse surface gave 6490 ± 125 BP (Sissons and Brooks, 1971), thus providing a range for the age of culmination of the Main Postglacial Transgression and of the Main Postglacial Shoreline in the area. Sissons (1983a) has indicated that the transgression culminated at about 6800 BP in the Western Forth Valley, an interpretation supported by more recent radiocarbon dating (Cullingford *et al.,* 1991).

In a very detailed study of their altitudes, Sissons (1972b) demonstrated that both the Main Postglacial Shoreline and the shoreline of the Main Buried Beach in the area east of the moraine had been faulted or warped at two locations. Since between these points the gradients of the shorelines resulting from isostatic uplift were the same, it was concluded that during the period between the formation of the two shorelines (around 3000 years), there had been no differential uplift in the area except at the dislocations. This demonstration of dislocation and nonuniform uplift has since been corroborated by studies elsewhere in Scotland, and may indicate that raised shoreline altitudes in isostatically affected areas may be more complex than had been previously thought.

A curve of relative sea-level change for the area of the morainic arc, for the period from 10,500 to 4000 BP, together with a curve of land uplift for the last 10,000 years for the same area has been published by Sissons and Brooks (1971).

Inchie

The site (Site I, (Figure 13.6)) stretches from Port of Menteith in the north to Inchie Farm [NN 592 000] in the south. It is bordered by the Lake of Menteith to the west and extends along the Goodie Water to the east. This area contains arguably the most distinctive part of the morainic arc and includes a transect along the Goodie Water where Loch Lomond Readvance outwash descends beneath buried beach and later Holocene deposits.

The northern limb of the morainic arc runs from north to south through this area, as an elongate belt consisting of many small ridges, each aligned across the main valley. These small ridges are rarely more than 5 m high, although the moraine reaches over 30 m above the adjacent lake. The surface of the moraine is furrowed in places by sinuous meltwater channels, leading eastwards, and is breached at three places by very deep channels with coarse gravels on their floors. The few exposures in the area indicate that the composition of the ridges is complex, with shelly marine clay, till and sands and gravels having been seen. It is likely that the area was formed by an advancing glacier pushing a variety of deposits before it. The marked asymmetry of the moraine ridge as a whole is in agreement with this interpretation, the steeper slope facing up-valley.

The section where Simpson (1933) reported evidence for a readvance was near Inchie Farm, probably close to [NN 592 0000]. He found 10 ft (3 m) of grey clay with fragments of *Mytilus edulis* (L) overlain by 30 ft (9.1 m) of sand and gravel. In 1967, Sissons identified a similar sequence near that location and on. the lake shore, and obtained a radiocarbon date of 11,800 ± 170 BP (1–2234) for a specimen of *Mytilus edulis* (L) (Sissons, 1967b), concluding that the readvance had occurred during the climatic deterioration at the end of the Lateglacial, the Loch Lomond Stadial. The fauna from the grey clay in Sisson's section (S. M. Smith, in Gray and Brooks, 1972) is as follows:

Littorina littorea (L)

Littorina obtusata (L)

Buccinum undatum L

Mytilus edulis (L.)

Nuculana pernula (Müller)

Chlamys sp.

Macoma sp.

Gray and Brooks (1972) also concluded that pollen from the grey clay indicated a Lateglacial Interstadial age for the deposit, and a largely open habitat locally was suggested by the low percentages of arboreal pollen. Taken with the stratigraphical evidence, these observations further support the correlation with the Loch Lomond Readvance.

The deep channels through the site carried outwash deposits eastward, as is indicated from the coarse sands and gravels on their floors. The largest channel, in the south of the site, contains a wide outwash terrace, part of which occurs on the proximal side of the moraine, indicating that it was deposited as ice began to waste back. This terrace, near Inchie Farm, slopes eastwards from 23.5 m OD. Beyond the moraine it descends beneath the carse clays, but its descent can be followed in the banks of the Goodie Water, where it passes beneath peat and fine-grained grey sand. The sequence was traced by Sissons *et al.* (1965) in exposures and boreholes and is shown in (Figure 13.7). The outwash descends to at least 9 m OD and it was concluded that relative sea level at the time of deposition lay below that altitude. The fine grey sand above has a level surface at 11 m OD and was interpreted as forming part of the Main Buried Beach, which thus appears to have accumulated following a marine transgression across the outwash. The peat above the sand demonstrates a marine regression, and the estuarine (carse) clay which overlies this peat, and reaches 14.7 m OD here, was laid down during the Main Postglacial Transgression.

Although the floors of the channels at the northern end of the moraine in this area descend to below 20 m OD there is no indication that the carse clays were deposited in them, and therefore no indication that the sea at the culmination of the Main Postglacial Transgression entered the Lake of Menteith.

Thus the landforms and deposits at Inchie demonstrate glacial advance, retreat and subsequent relative sea-level changes. Though the sequence is known in detail, it is interesting that so far no evidence of the High Buried Beach has been found in this area. It may be that the beach is confined to the sides of the depression through which the Goodie Water flows, in a similar manner to the situation at Easter Garden, discussed below.

Easter Garden

The site (Site II, (Figure 13.6)) lies on the left bank of the Garden Burn near Arnprior [NS 612 948], south of the River Forth. It includes the ice-distal (outer) portion of the morainic arc, together with carselands south of the Forth and along the Arngibbon and Garden Burns. The area was studied in detail by Sissons (1966). It contains some fine morainic topography, but is particularly notable for the sub-carse deposits, which include outwash gravels, together with High, Main, and Low Buried Beaches.

The southern limb of the morainic arc consists of a large number of small ridges intersected by shallow meltwater channels. It is kettled in places and appears to be largely composed of sands and gravels. To the south of the site, the moraine is dissected by a large meltwater channel system, in which the main channel exceeds 20 m in depth. This was probably excavated largely by proglacial meltwaters.

The carseland stratigraphy in this area (Sissons, 1966) reveals a number of interesting features. South of Easter Garden [NS 607 957], the carse-lands at the foot of the moraine are underlain by outwash gravels, which come from the mouth of the meltwater channel to the south. The surface of these gravels is slightly irregular, but falls north-eastward down to 11 m OD. Between Easter Garden and the moraine, and in a small area south of Easter Garden, the outwash is overlain by a deposit of silty sand which is pinkish or pale brown in colour except at its surface, where it is grey. In places, this deposit is laminated and its surface is level at about 12 m OD. It is part of the High Buried Beach (Sissons, 1966) and this location is the farthest up-valley it has been found.

South of Easter Garden and north of the Arngibbon Burn, the outwash surface and High Buried Beach have been dissected by a channel up to 200 m broad and 3 m deep, which appears to originate at the mouth of the meltwater channel system referred to above. This channel is largely floored with deposits of a grey silty fine-grained sand with occasional bands of silt or clay, lying at around 11 m OD. Where the channel ends north-east of Easter Garden, these sediments form a wide surface lying at 10.7 m OD. Sissons identified this as the Main Buried Beach. North of the abandoned railway line, a sharp break of slope occurs in the Main Buried Beach deposits and a lower area of grey silty clay, becoming more sandy with depth, ensues, lying at 6.4 m OD. This has been interpreted as the Low Buried Beach.

The buried surfaces of the outwash, and the High, Main and Low Buried Beaches are covered in peat, which becomes thicker over the lower surfaces. This peat is, in turn, overlain by carse clays, which reach 15 m OD in this area and belong to the Main Postglacial Shoreline. In some areas nearby the carse clays are covered in peat.

At the mouth of the large meltwater channel system mentioned above, the Arngibbon Burn has deposited an alluvial fan, which extends into the southern part of the site (Sissons *et al.,* 1965). Boreholes through the fan show that it overlies carse clay, whereas boreholes nearby in the floor of the main meltwater channel show peat, overlying lacustrine clay, which overlies estuarine (carse) clay. The alluvial fan was deposited across the mouth of the meltwater channel, and it seems that here the alluvial fan, built out across the carse clay, temporarily dammed a lake in the mouth of the meltwater channel system.

The sequence of events recorded in this area is therefore as follows. First, a readvance of ice formed a large moraine belt, and meltwaters discharged proglacially across it. At the southern end of the moraine a large proglacial meltwater system deposited an outwash fan in a northeasterly direction. The lowest elevation of the outwash, 8 m OD, indicates that relative sea level could not have been higher than this at the time. Then, relative sea level rose, and the High Buried Beach was deposited on part of the outwash surface. The ice must have been at the moraine during this period, because a large channel, emanating from the mouth of the meltwater channel system, was subsequently cut in both the outwash and the High Buried Beach. The size and position of this channel suggests that it was probably cut by proglacial meltwaters. Subsequently, relative sea level fell and deposits of the Main Buried Beach were laid down across lower parts of the outwash and in the channel. A further fall in relative sea level was followed by deposition of the Low Buried Beach. Eventually, relative sea level fell further and peat accumulated on the surfaces revealed. Later, the Main Postglacial Transgression led to the deposition of the carse clays. Subsequently, relative sea level fell again, and as peat began to accumulate on the carse clay surface, a small fan was built up by the Arngibbon Burn at the mouth of the large meltwater channel system, trapping a small lake in the lower part of the main channel. The lake eventually filled with clay, and peat also accumulated on these sediments.

West Moss-side

South of the Farm of West Moss-side [NS 648 996], an area of East Flanders Moss (Site III, (Figure 13.6)) has provided a focus of interest for studies of Holocene relative sea-level changes. It is in this area that peat continued to accumulate during the Main Postglacial Transgression, forming an island in the then expanded estuary of the Forth. The peat stratigraphy of this area has been examined in detail by Smith (1965) and by Sissons and Smith (1965b).

East Flanders Moss is a remnant of a much more extensive peat bog that once covered the carselands of the Forth Valley. Clearance of the peat in the Forth Valley began in the eighteenth century (Tait, 1794) and ended in 1865 (Cadell, 1913). The termination of most peat clearances appears to have been for economic or social reasons, but near West Flanders Moss there is evidence that as the clearance progressed, the farmers encountered an increasingly boggy carse surface, which declined in altitude sharply.

In 1950, a survey of East Flanders Moss was undertaken by the Department of Agriculture for Scotland (Peat Section). From a number of boreholes they found that the peat was widely underlain by the level surface of the carseland, but that near West Moss-side a depression of over 4 m lay beneath the peat. Durno (1956) undertook pollen analysis of a core from this depression, finding that the basal peat began to accumulate in Zone V of the Jessen–Godwin system of pollen zonation, significantly earlier than peat elsewhere on the carseland surface. He concluded that the marine transgression in which the estuarine (carse) clay had accumulated had ended east of East Flanders Moss.

Smith (1965) and Sissons and Smith (1965b) later examined the stratigraphy in detail (Figure 13.8). They found that beneath the peat the carse clay formed a wedge at the edge of the depression. They identified a similar sequence at West Flanders Moss, west of the morainic arc. They also found that the peat at the base of the depression in East Flanders Moss continued beneath the carse clay, and that it rested upon a remarkably level surface lying at *c.* 10.0 m OD. They concluded that the surface upon which the peat had commenced accumulating was that of a buried beach (later identified as the Main Buried Beach by Kemp (1976), and that this peat had managed to continue accumulating in a small area throughout the Main Postglacial Transgression. After the sea subsequently withdrew, the peat island expanded across the adjacent carse surface, at an altitude of approximately 12 m OD.

In West Flanders Moss, a thin (about 0.03 m) layer of grey, micaceous, silty fine sand has been identified within the carse and continuing into the peat, beneath the carse clay 'wedge'. This is thought to have been deposited during a North Sea storm surge (Smith *et al.,* 1985a; Haggart, 1988b) or more probably a tsunami event (Dawson *et al.,* 1988; Long *et al.,* 1989a). Recent work suggests that this layer may also be present beneath East Flanders Moss.

Easter Poldar

The detailed and often complex sub-carse stratigraphy in the Western Forth Valley can normally only be examined through detailed coring. However, at a number of sites along the Forth and Goodie Water, some elements of the stratigraphy can be examined in exposures. The best individual sites are along the river bank from Faraway [NS 615 964] to Easter Poldar [NS 647 972].

Near the Farm of Easter Poldar, on the left bank of the River Forth, an exposure in the carse clay and the underlying deposits was first recorded in 1964 (Smith, 1965). The sequence of deposits is as follows:

		Thickness (m)	Altitude (m) OD (surface= 12.56
5	Brown silty clay, with reed stems	4.31	8.25
4	Blue-grey silty clay, with reed stems	0.15	8.10
3	Woody peat	0.24	7.86

2	*Sphagnum* peat	0.09	7.77
1	Fine-grained blue-grey silty sand with reed stems, especially in the upper part (base not seen), to	0.06	7.71

In 1966, Sissons identified the surface of the fine-grained, blue-grey, silty sand (bed 1) as part of the Low Buried Beach. The presence of increasing numbers of reeds in its upper part suggests that the overlying peat may have started to accumulate shortly after the sea withdrew from the surface. The peat (beds 2 and 3) is much compressed, but the transition from *Sphagnum* peat (bed 2) to a more woody peat (bed 3) indicates that conditions became less moist. The sediments above the peat are estuarine carse clay (beds 4 and 5), the brown coloration in the upper part (bed 5) probably being due to oxidation from the face of the exposure.

Interpretation

The assemblage of landforms and the sequences of deposits in the Western Forth Valley are among the most detailed for the Late Devensian and early Holocene in Scotland. The glacial and glaciofluvial landforms represent arguably the finest evidence for a readvance ice limit and subsequent ice decay anywhere in the British Isles, and the detail of the record of relative sea-level change is unsurpassed in Scotland.

At a number of other sites (Loch Etive, South Shian and Balure of Shian, and Rhu Point) it can be demonstrated that the Loch Lomond Readvance glaciers discharged into the sea or constructed outwash plains graded to sea level. However, it is only in the Western Forth Valley that a specific sequence of sea-level changes can be established at, or close to the time of the maximum of the readvance.

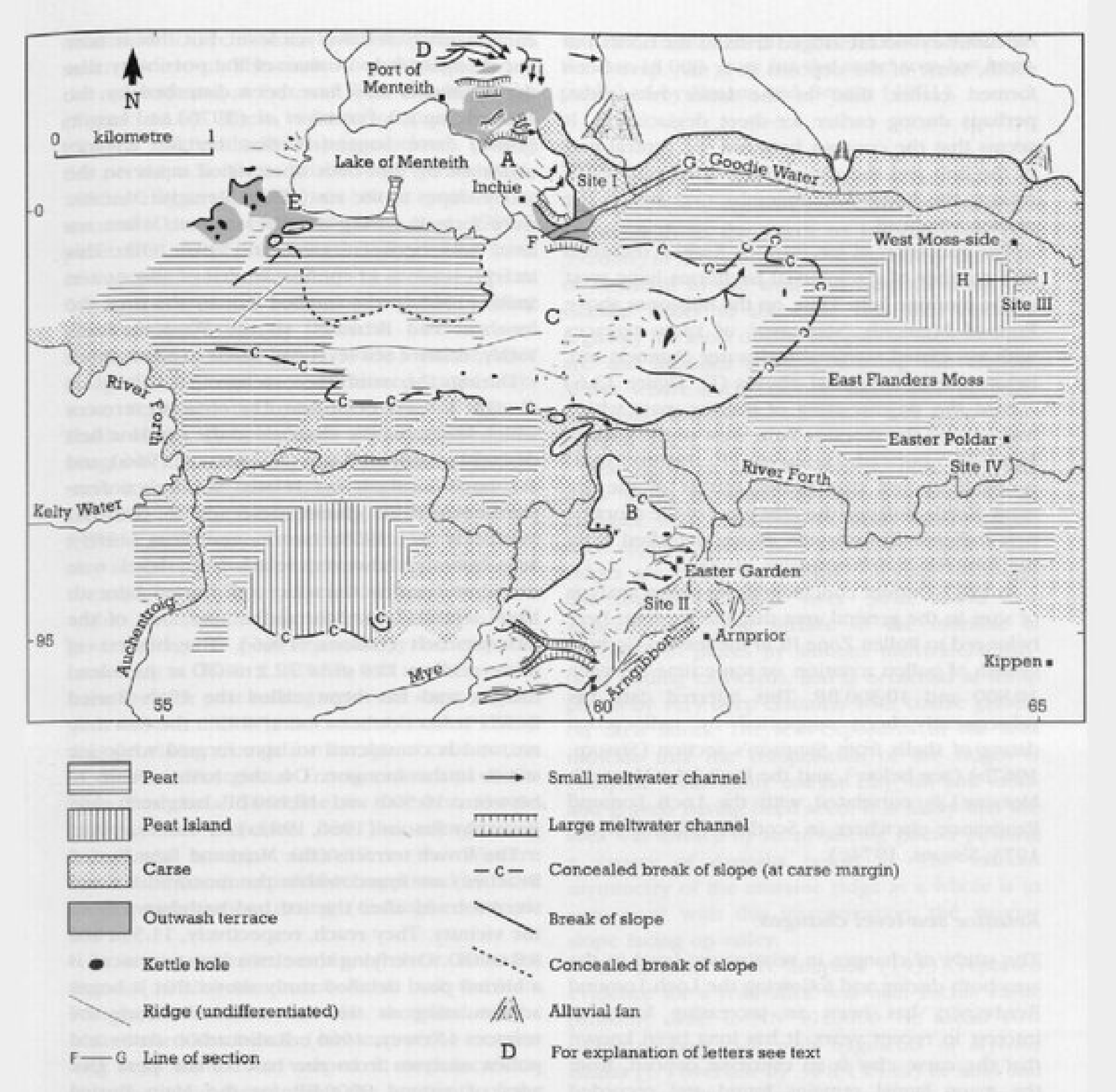
Early to middle Holocene sea-level changes have been studied in greater detail in the Western Forth Valley than in any other locality in Scotland. Both the sedimentary sequences and the landforms arising from sea-level change have been analysed, unlike in most areas where one or the other approach to sea-level change studies has been adopted. In consequence, fundamental information on the nature of isostatic uplift has been established in this area, notably the role of fault-reactivation and block movement. This last aspect has had important consequences for the study of neotectonic activity in Scotland.

The geomorphology of the morainic system has yet to be fully mapped, but it is evident from the details so far revealed, especially from exposures, that the moraine sediments will greatly repay further study. In this regard, two sites where the moraine is displayed (Inchie and Easter Garden) will be crucial. At all the key sites discussed here, the carse and sub-carse deposits have yielded a remarkably detailed story, but further work is needed to reveal the extent of tsumani or storm surge deposits, the progress of marine transgression and regression, and in particular further evidence for neotectonic activity. It is evident that the Western Forth Valley will play an important part in future scientific enquiry into both glacial events and relative sea-level changes in Scotland.

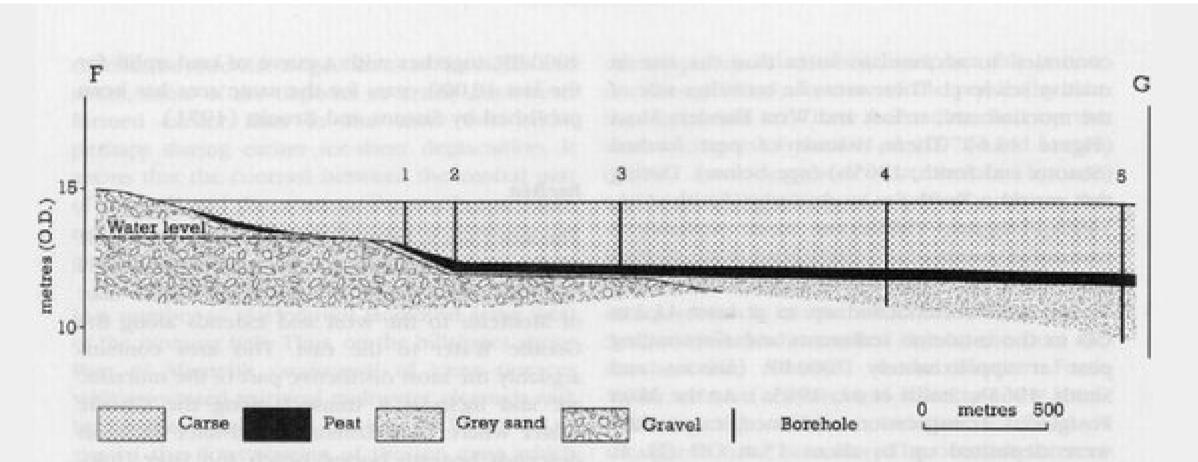
Conclusion

The Western Forth Valley is a critical reference area for studies of the Loch Lomond Readvance, and particularly for the sequence of sea-level changes that occurred around and following the maximum of the ice readvance (approximately 10,500 years ago). The key interest includes a complex of moraine ridges and outwash sediments (deposited in front of the glacier by meltwater rivers) and a sequence of buried estuarine deposits. The latter provide the most detailed record of sea-level changes in Scotland at the time of the readvance and later during early to middle Holocene times (approximately 10,500–6000 years ago). The area has a long history of research, and its landforms and sediments have been studied in great detail. In addition, the results of the work provide a standard framework of sea-level changes for comparison with other areas. Furthermore, the Western Forth Valley has allowed important insights into the processes that accompany isostatic recovery, that is, upward movement of the Earth's crust following ice melting.

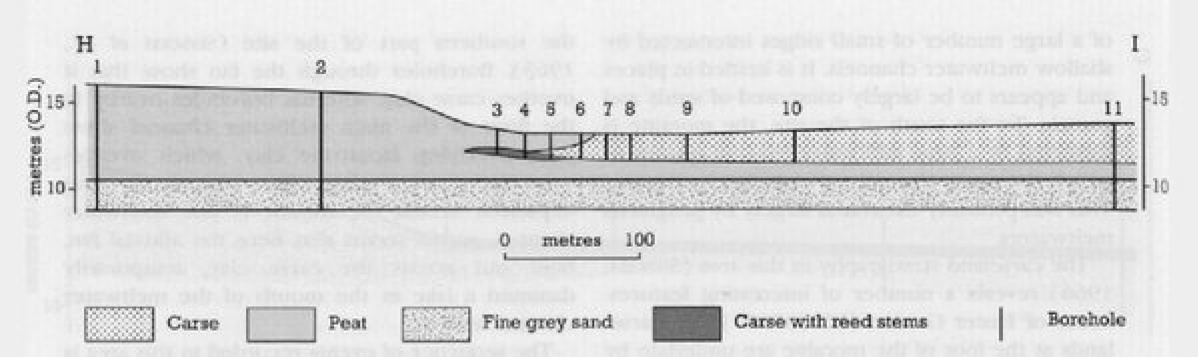
References



(Figure 13.6) Geomorphology of the Western Forth Valley.



(Figure 13.7) Western Forth Valley: section along the Goodie Water (from Sissons et al., 1965). See Figure 13.6 for location of section.



(Figure 13.8) Western Forth Valley: section at West Mossside, East Flanders Moss (from Sissons and Smith, 1965b). See Figure 13.6 for location of section.