THE GEOMORPHOLOGICAL SETTING OF FLANDERS MOSS

D.E. Smith and L.K. Holloway

Introduction

Flanders Moss (East Flanders Moss) lies at the western limit of the Forth Valley lowland (Figure 1). In this account, the main features of the lowland as a setting for Flanders Moss are described, with particular emphasis being given to the impact of sea level change during and following the last glacial episodes. Field evidence for late Quaternary relative sea level change in the western Forth lowland, together with the evolution of the Moss, is discussed.

Geology and Glaciation

The lowland may well have originated during the Cretaceous Period from an eastward draining valley superimposed across the area from a uniform cover of chalk (*e.g.* Bremner, 1942; Linton, 1951, and as summarised in Sissons, 1967, 1976). However, if this mantle of chalk did exist, it has now been removed by erosion, and it is the older rocks beneath which now provide the geological setting. The underlying geology of the Forth lowland is largely sandstones of the Devonian Old Red Sandstone. The Highland Boundary Fault crosses the lowland at its western end and marks the edge of the largely Pre-Cambrian igneous and metamorphic Grampian Highlands. Towards its eastern end, near Stirling, a constriction in the lowland is caused by Carboniferous dolerite intrusions, where the Wallace Monument and Stirling Castle now stand (*e.g.* MacGregor and MacGregor, 1948).

The present form of the Forth lowland owes much to the two to three million years of repeated Quaternary glaciations. On many occasions, ice streams would have flowed eastwards through the lowland, ultimately producing a wide but relatively shallow rock trough (rockhead rarely exceeds a depth of 10 m below Ordnance Datum). The last ice to fully occupy the lowland was that of the maximum of the last glaciation, the Devensian, probably somewhere between 17 000 and 20 000 yr BP. As this ice withdrew it left a landscape of streamlined ridges of till (boulder clay), principally on the northern side of the lowland and on neighbouring interfluves. These ridges are flanked at their lowland edge by fluvioglacial outwash terraces. A major stage in the retreat of Devensian ice was the Perth Stage, when the retreating ice margin stabilised in the Kincardine area, then across the constriction in the lowland at Stirling, before finally withdrawing from the lowland sometime before *circa* 13 500 yr BP (Sissons, 1974) (Figure 1).

This episode of glaciation was not the last occasion on which ice occupied parts of the Forth lowland. After a period of ameliorating climate (the Windermere Interstadial), a worsening of climate led to the re-expansion of glaciers in the Highlands and an ice stream re-entered the head of the lowland during the Loch Lomond Readvance of *circa* 11 000-10 000 yr BP. This event formed a prominent moraine complex crossing the lowland between Port of Menteith to the north and Arnprior to the south. Termed the Menteith Moraine, it consists of a series of parallel ridges of clays, silts, sands and gravels, and is intersected by breaches through which meltwater was discharged. Ultimately, Loch Lomond ice withdrew as climate ameliorated at the beginning of the present episode of warm climate (the Flandrian, or Holocene).

It is around and amongst the landforms of ice advance and decay that the deposits of successive sea levels accumulated to form the basis for the development of Flanders Moss. Figure 2 depicts the setting of the Moss in the context of these glacial, fluvial and estuarine deposits.

Sea Level Change in the Forth Lowland

The sequence of changes in sea level in the Forth lowland during and following the decay of both Perth and Loch Lomond ice, and during the subsequent Flandrian, was broadly established in the 1960s by Sissons (*e.g.* 1965, 1966). Prior to this, the area had long been a focus of sea level studies, with Jamieson (1865) having established the concept of glacio-isostasy (in which the weight of ice depressed the land, and subsequent ice decay brought about renewed land uplift), from his observations made near Blairdrummond. Based on detailed and extensive morphological and stratigraphical information, Sissons produced a model of relative sea level change in the Forth lowland, which reflects the interaction of glacio-isostasy and sea level change (Figure 3). In this model, based on many altitudinal measurements, the shorelines are shown declining eastwards, reflecting greater land uplift in the west as a consequence of thicker ice masses in that area.

In Sissons' model, the decay of the Perth Stage ice was accompanied and succeeded by an invasion of the lowland by the sea. Morphological evidence (raised marine terraces along the sides of the lowland) reflects a staircase of former shorelines, the lower members of which extend progressively farther westward as a result of marine invasion followed by land uplift as the ice decayed. Stratigraphical evidence from the the eastern lowland discloses a mélange of glacial deposits above the sandstone bedrock. This is overlain, probably without major lacunae, by estuarine silts and clays, again supporting a marine invasion during or following deglaciation.

The model envisages a continued fall in relative sea level throughout the Windermere Interstadial. This was succeeded by a rise, or stabilisation, in sea level as the climate deteriorated with the advent of the Loch Lomond Stadial. This is thought to have resulted in the erosion of some areas of bedrock, together with underlying glacial and estuarine sediments, to produce a lag gravel layer termed the Main Lateglacial Shoreline. This, now buried, feature can be traced most notably east of Stirling at *circa* -6 m OD (Sissons 1969, Sissons and Rhind, 1970), and possibly also in the western Forth lowland, reaching about 7 m above OD (this paper).

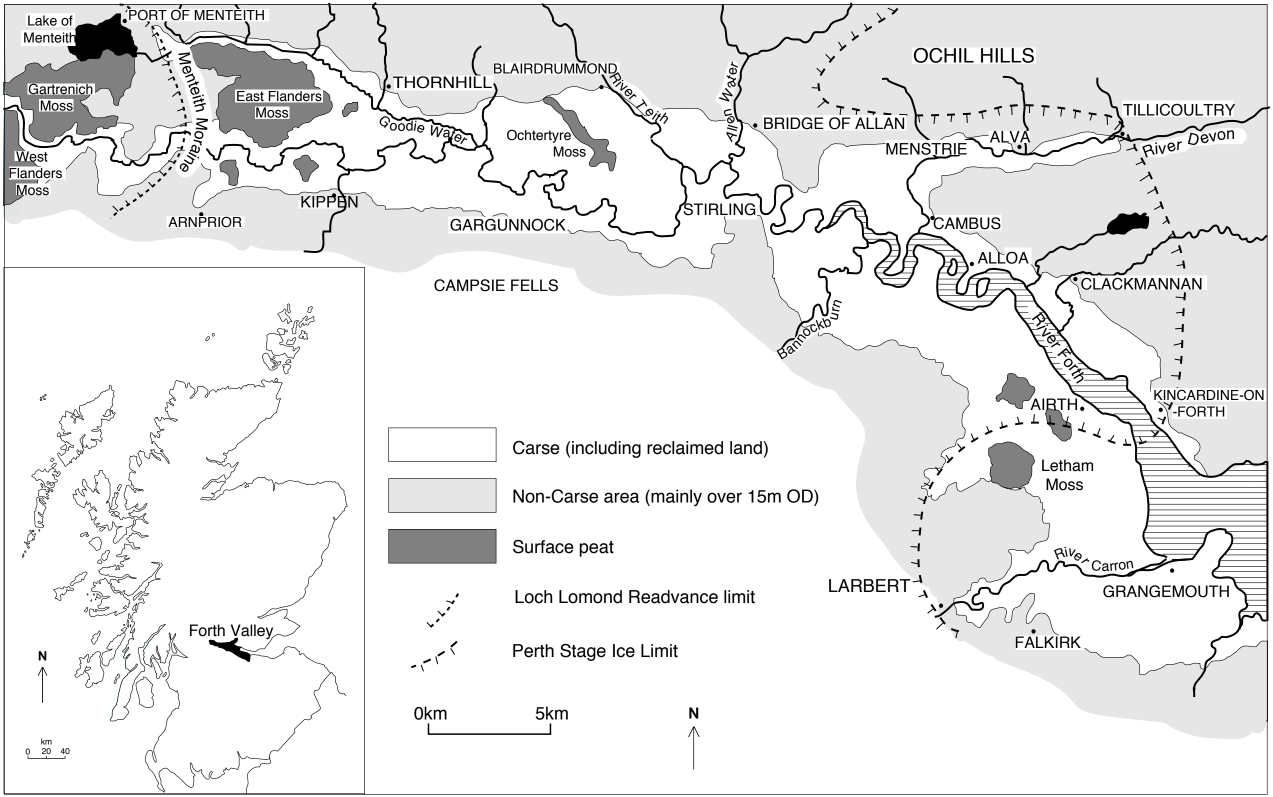

Figure 1 The Forth Valley Lowland (Carselands) (after Kemp, 1979).

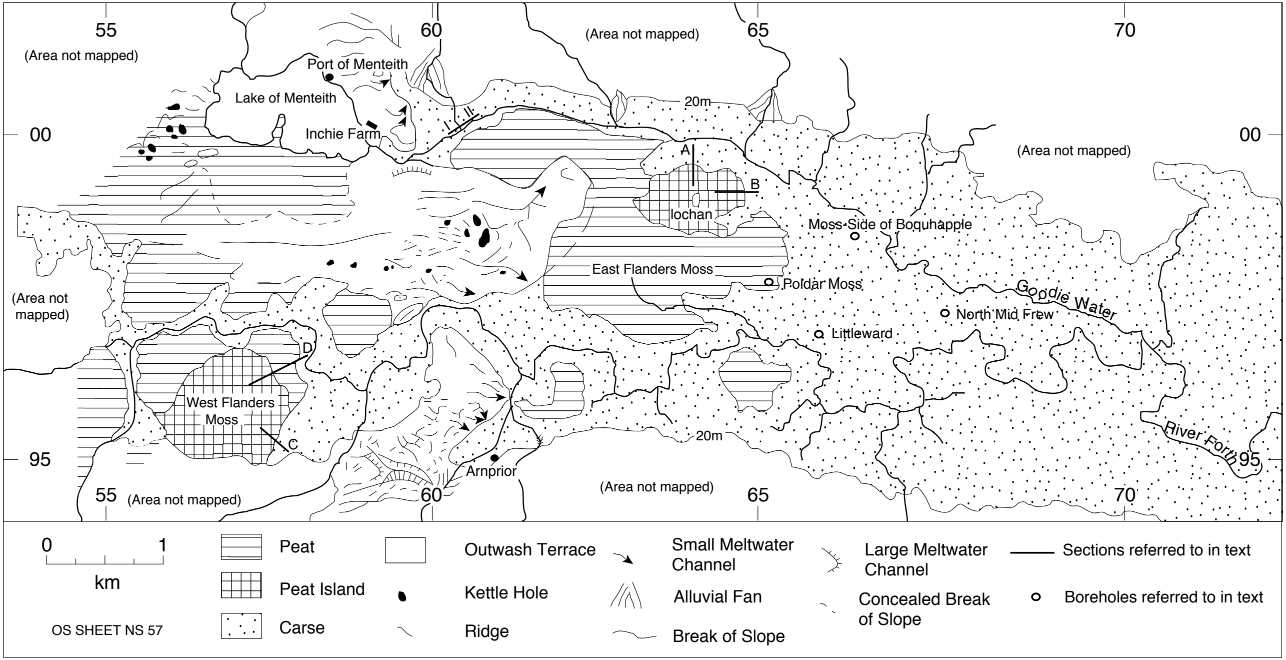

Figure 2 The Geomorphology of the Western Forth Lowland (after Smith, 1993).

The subsequent arrival of a Loch Lomond glacier into the head of the lowland probably removed most of the depositional features which had accumulated in that area during and following the decay of Perth Stage ice. Incorporated in the deposits of the Menteith Moraine are estuarine deposits containing shells. Near Inchie Farm (Figure 2) a specimen of *Mytilus edulis* from these deposits has been dated at 11 800± 170 yr. BP (*i.e.* radiocarbon years before 1950, the benchmark year for radiocarbon dating) (Gray and Brooks, 1972). Evidently the Loch Lomond glacier at the head of the valley had advanced into an area of estuarine sediments, disturbing them and mixing those sediments with deposits of the moraine.

Sea levels at the head of the lowland when the ice formed the Menteith Moraine are unknown. In terms of establishing a minimum sea level for the Loch Lomond Stadial, it is known that the fluvioglacial sand and gravel deposits which formed at and in front of the Loch Lomond ice margin in the western end of the valley (and as deployed through the gaps in the Menteith Moraine), can only be traced in boreholes for a limited distance and, as yet, have never been traced descending to altitudes below that for the Main Lateglacial Shoreline feature. This suggests that the minimum Loch Lomond Stadial sea level never fell lower than it did during the formation of the Main Lateglacial Shoreline (*circa* 7 m OD in the western lowland). Current understanding is that there was in fact a marine transgression, as Loch Lomond Stadial ice still lay at the moraine. Estuarine silts and clays (*circa* 13 m OD) have been traced on top of areas of outwash, forming a feature known as the High Buried Beach (in fact an estuarine terrace deposit, rather than a "beach" *sensu stricto*) (Figure 3). The lack of this feature in the sedimentary sequence behind the moraine is taken as evidence of its contemporaneity with the presence of an ice mass at the head of the lowland. A maximum age of *circa* 10 300 yr BP has been estimated by Sissons (1966) for this feature.

Ultimately, the Loch Lomond glacier decayed and the development of an extensive estuarine deposit, below the altitude of the High Buried Beach, points to renewed sea level fall. This feature, termed the Main Buried Beach, heralds the start of the accumulation of Flanders Moss. The Main Buried Beach, at its upper surface, lies consistently at *circa* 11 m OD in the western Forth lowland. Unlike the preceeding terrace, the Main Buried Beach is present both east and west of the Menteith Moraine (Sissons and Smith, 1965), demonstrating that it formed after ice had vacated the area. As sea level continued to fall, the upper surface of the Main Buried Beach became subaerially exposed, initially in an intertidal environment and eventually lying above the influence of the tidal cycle. Exposures of this deposit, visible in the banks of the Forth at Faraway, disclose macrofossil evidence of reedswamp development at its surface, and both pollen analyses (*e.g.* Newey, 1966, Sissons and Brooks, 1971 and Brooks, 1972) and diatom analyses (*e.g.* Robinson, 1993) indicate gradually decreasing marine influence as peat accumulation began across the sediment surface. Radiocarbon dates from the base of the peat at several locations by Robinson (1993) indicate that peat accumulation began around 9600 yr BP, perhaps as early as around 9900 yr BP. Obtaining an accurate

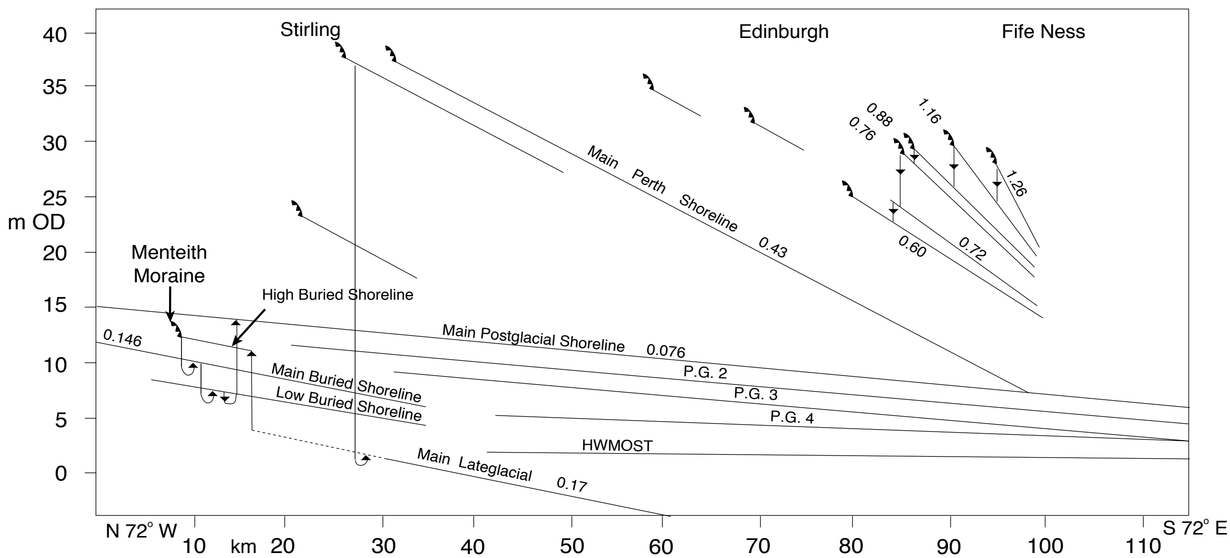

Figure 3 Height-Distance Diagram of Shorelines in South-East Scotland. Gradients are in mkm^{-1} (after Smith 1965 & Sissons, Smith and Cullingford 1965, as previously published in Smith, 1997).

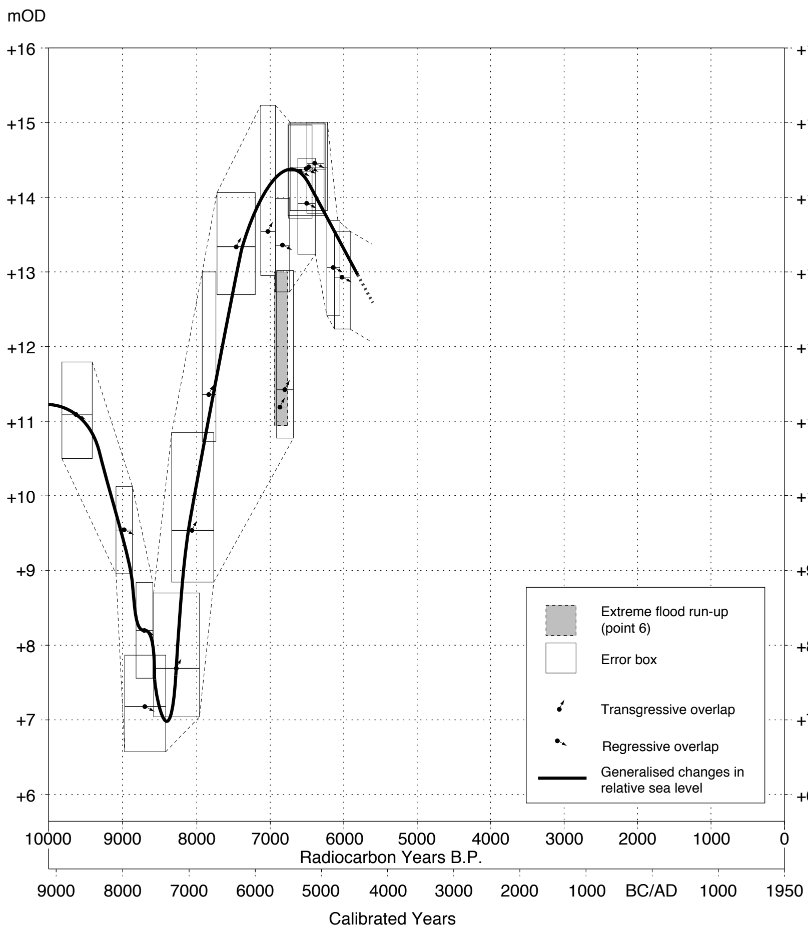

Figure 4 Flandrian Relative Sea Level Change, Western Forth Lowland (after Sissons and Brooks, 1971; Robinson, 1993).

estimate of the age at which the first Flanders Moss peat began to accumulate is problematic, given that existing ages span the 9000-10 000 yr BP radiocarbon timescale which has two known "plateau" periods where true radiocarbon ages are difficult to determine with certainty (Kromer, 1991).

Below the Main Buried Beach lies a third estuarine terrace, formed in response to a trangressive pulse interrupting the generally regressive sea level trend of the early Flandrian. Termed the Low Buried Beach, and reaching 8 m OD, this deposit is confined to a narrow zone broadly along the axis of the Forth lowland (Sissons, 1966). This surface also became abandoned as sea level continued to fall and peat accumulation developed across it. Abandonment of the Low Buried Beach is placed at about 8700 yr BP by Robinson (1993). It seems likely that by *circa* 8500 yr BP, the three estuarine surfaces of High, Main and Low Buried Beaches were extensively occupied by peat mosses, perhaps presenting a similar appearance to the peat-covered carselands of the early eighteenth century before peat clearance began. Strangely, the High Buried Beach has not yet been found to possess a peat cover older than that across the Main Buried Beach, implying that conditions may have been inimical to the accumulation of peat on its surface until the abandonment of the Main Buried Beach.

The fall in sea level in the Forth Estuary was apparently arrested by about 8400 yr BP, when at Airth, to the east of Stirling, peat became overlain by silts and clays of the early carseland deposits (Godwin and Willis, 1961). Relative sea level graphs of Sissons and Brooks (1971) and Robinson (1993), here amalgamated in a composite graph, chart the rise in the western Forth lowland (Figure 4). For each datum, the sea level index points plotted are comparable points marking the approximate limit of the Mean High Water Spring tides (mHWS), and are surrounded by boxes giving the likely errors of these points according to recent studies (*e.g.* Cullingford, Castledine and Gotts, 1980). The marked rise in sea level, the Main Postglacial Transgression (named by Sissons in 1974), was rapid, amounting to perhaps 4.5 mm yr^{-1} from data obtained by Robinson (1993). As the transgression progressed, most of the peat areas then developing were submerged and buried beneath accumulating carse silts and clays. However, on the sites of both West and East Flanders Moss, peat islands were able to persist and resist inundation by the carse sea (see Figure 2). The areas of these islands have been determined by detailed boring and with reference to Peat Survey of Scotland borehole records (Smith, 1965; Sissons and Smith, 1965; Cullingford, Smith and Firth, 1991). In East Flanders Moss, the island would have been about 2 km^2 as the transgression reached its maximum. Stratigraphically, the former islands can be detected today by identifying the limits of tapering wedges of carse sediment, which can be traced widely across East Flanders Moss.

Culmination of the Main Postglacial Transgression was achieved at about 6900 yr BP according to Robinson (1993) from data obtained across one such tapering wedge of carse sediment extending into West Flanders Moss. The carse sediments of the western Forth lowland reach an altitude of not more than 14.9 m OD in and around the mosses at the Main Postglacial Shoreline. A recent map showing altitudes for this shoreline across Scotland, analysed by Trend Surface Analysis to produce a contour map, effectively an isobase map (Figure 5), show it to have attained its highest value in the western Forth lowland. Dates on deposits associated with the shoreline demonstrate that it is time-transgressive across Scotland, ranging in age from *circa* 6900 yr BP to *circa* 6000 yr BP. Thereafter, sea level fell back, probably in stages, revealing lower terraces in the carselands to the east of Flanders Moss (Smith, 1968), to achieve its present levels in the Forth estuary, possibly sometime after 2000 yr BP (by inference from sites elsewhere in Scotland). As sea level fell, peat accumulation continued at East Flanders Moss, as well as on the then exposed carseland surface, leading to the widespread development of the lowland raised mosses of the Forth valley, visible before the moss clearances.

Recent stratigraphical investigations at West Flanders Moss, have provided evidence for a major marine flood event in the Forth lowland which appears to have occurred close to the culmination of the Main Postglacial Transgression. At Over Easter Ofference, in the buried peat just below a tapering wedge of carse sediment, a sheet of micaceous silty fine sand has been traced (Sissons and Smith, 1965, Figure 9, transect D, this paper). Diatom analysis (Robinson, 1993) revealed the sand layer to be rich in broken fragments of marine and estuarine algal species. Additionally, its stratigraphical position (surrounded above and beneath by predominantly terrestrial peats), suggests that the sediment sheet accumulated during a high energy event. The underlying peat was dated to *circa* 6870 yr BP (Robinson, 1993) and the sand layer is thought to correspond in origin to other similar deposits known to be widespread in eastern Scotland (Smith, Cullingford and Haggart, 1985). It is believed that this deposit was laid down during a tsunami associated with a large underwater landslide on the continental slope off south-west Norway, the Second Storegga Slide (Dawson, Long and Smith, 1988) and it is believed to have reached eastern Scotland at about 7100 yr BP (the slight age difference to the Over Easter Offerance date being within a combined radiocarbon and sampling error). Although traceable as a continous sediment sheet at Over Easter Ofference, the deposit cannot be traced extensively thoughout all peats of similar age in the western Forth lowland. Macrofossils found in corresponding sediments elsewhere in Scotland, and from Norway, indicate an event in the autumn, and the distribution of the layer across eastern Scotland suggests that it was laid down in the Forth lowland at perhaps mid or low tide on the tidal cycle, providing an explanation of why the sand deposit is not more extensively found.

Field Evidence for Sea Level Change at East Flanders Moss

The majority of field evidence for sea level change in the western Forth lowland has been gained from sites around the periphery of East and West Flanders Moss. In addition to this informtion, recent sedimentological work on four deep boreholes (undertaken by the Dutch Geological Survey in 1995), at Moss-Side of Boquhapple, Poldar Moss, Littleward and North Mid Frew, located to the east of East Flanders Moss, illustrates the influence that relative

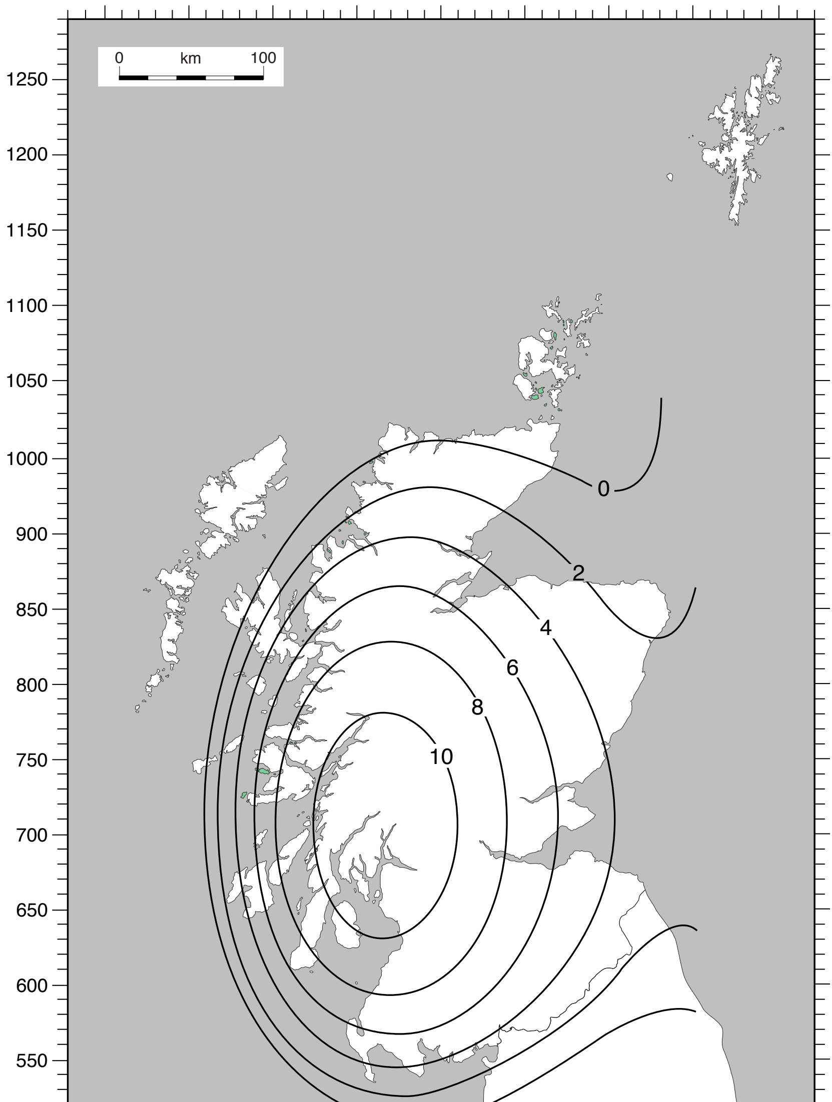

Figure 5 Isobases for the Main Postglacial Shoreline (values in metres above High Water Mark of Spring Tides) as Determined by Cubic Trend Surface (after Smith *et al.*, 1995)

sea level changes have had on the evolution of the Moss.

Some of the earliest evidence for sea level change in the Forth lowland can be seen along the Goodie Water channel to the north of East Flanders Moss, and was first interpreted by Sissons, Cullingford and Smith (1965). As the channel is followed draining south-east from the Lake of Menteith, it is flanked by sand and gravel terraces, a series of relict outwash terraces once deployed from the Loch Lomond ice margin through a breach in the Menteith Moraine (near Inchie Farm, Figure 2). These terraces fall consistantly in altitude along the Goodie Water channel, and eventually descend beneath the carse and occasional remnants of surface peat. Through excavations in the channel banks, the carse clay can be seen to rest on a buried peat layer overlying a blue-grey silty clay (Main Buried Beach) deposit, overlying the descending outwash material (Figure 6). This sequence represents an early Flandrian marine trangression followed by a marine regression and initiation of terrestrial peat growth, before another phase of marine inundation (Main Postglacial Transgression), and accumulation of the carse, the surface of which was then revealed following a subsequent fall in relative sea level allowing the surface peat to accumulate.

The Flandrian estuarine and peat sequence to the east of East Flanders Moss is not thought to rest on outwash gravels discharging from the Menteith Moraine ice limit, for as borehole evidence from Moss-Side of Boquhapple reveals, the Flandrian sequence overlies earlier Lateglacial deposits of shelly red clay with stones, capped with a thin gravel layer. Molluscan and ostracod evidence suggest that the pink clay represents a fjord-style, cool water, estuarine environment. AMS radiocarbon assays suggest that the clay is Winderemere Interstadial in age (*circa* 13 000 yr BP). Ostracod evidence confirms this deposit is probably an undisturbed, down-valley continuation of the estuarine material displaced by advancing ice and incorporated into the Menteith Moraine at the head of the valley. Sea level interpretations are tentative, but from at least 13 000 yr BP to 11 800± 170 yr BP (the date on a shell from the Mentieth Moraine, Gray and Brooks, 1972) high relative sea level conditions can be envisaged for the area.

Above the pink clay deposit frequently lies a *circa* 10cm thick gravel deposit. In the case of the borehole at North Mid Frew, the gravel contains molluscan fragments. It is believed that this feature (traced at *circa* +6-7 m OD in the western lowland) can be correlated with the lag gravels to the east of Sirling (at *circa* -6 m OD), and represents the western extent of the Main Lateglacial Shoreline, envisaged by Sissons (1969), reflecting low sea level conditions during the Loch Lomond stadial.

The Flandrian record itself, to the east of the Moss, is similar to that visible in the banks of the Goodie Water to the west (Figure 7). The Poldar Moss core demonstrates the surface peat cover overlying the carse clays. The consistency in altitude of the lower contact of the buried peat surface between Poldar Moss and Moss-Side of Boquhapple illustates the flat shoreline surface of the Main Buried Beach as it became colonised by terrestrial vegetation. Notably, in the core from Littleward, the buried peat lies at just over 7 m OD, representing the colonization of the exposed Low Buried Beach surface by vegetation. The absence of buried peat at North Mid Frew possibly reflects erosion by the rise in sea level of the subsequent Main Postglacial Transgression.

Laboratory analysis of the size of particles forming the suite of Flandrian estuarine deposits can be used as a proxy indicator of energy conditions in the estuary at the time the minerogenic deposits accumulated (Figure 8). It is consistently the case that the lower portions of both the carse sediments and the Buried Beach deposits are generally sandier and frequently laminated. The Buried Beach deposits have been found to be coarser grained, with a higher percentage of sand-sized grains relative to the predominantly clay- to silt-sized grains forming the carse sediments. The dynamics of estuarine sedimentation are complex, but it can be noted that peat accumulation follows the "quiet water" environment, near the upper portion of the estuarine material, when clays and silts predominate. Conversely, at North Mid Frew, where the buried peat is absent, the carse sediment contains a significant proportion of sand, suggesting that energy conditions during the Main Postglacial Transgression were high enough to erode any intervening peat deposits at this locality.

It can be observed that at *circa* 12 m OD a clustering of laminations is frequently observable within the usually massive carse clays (Figure 8). In the case of the Poldar Moss and Moss-Side of Boquhapple cores, this is also accompanied by a coarsening in particle size (Figure 9). This may correlate with the minerogenic sediment sheets found within the peat (Sissons and Smith, 1965, and Robinson, 1993).

The Evolution of East Flanders Moss

Not only does Flanders Moss contain some of the most detailed evidence for Flandrian sea level change in Scotland, but the accumulation of these estuarine sediments has significantly determined the evolution of the Moss throughout the last *circa* 9000 years. Figure 9 illustrates the stratigraphic setting of the peat islands of West and East Flanders Moss, and the periods of marine inundation around the edges of these islands. New sedimentological information confirming the drop in energy conditions associated with the upper portion of the Buried Beach material (this paper), together with palaentological information demonstrating the tailing-off in marine influence in the overlying organic material with the transition from marine to terrestrial dominance (Robinson, 1993), illustrates how the environmental conditions of falling sea level allowed the initiation of Flanders Moss *circa* 9000 yr BP. The perpetuation of an island of peat in East Flanders Moss, as well as one in West Flanders Moss (Figure 2), whose vertical rate of accumulation evidently must have outstripped the rate of sea level rise associated with the Main Postglacial Transgression, can be partly explained by their geomorphological setting. The deepest zones of peat are to be found exclusively at the western limit of the Forth lowland. Here, marine erosion in the almost land-locked estuary would have been at its least influential. The two zones of deep peat are some distance

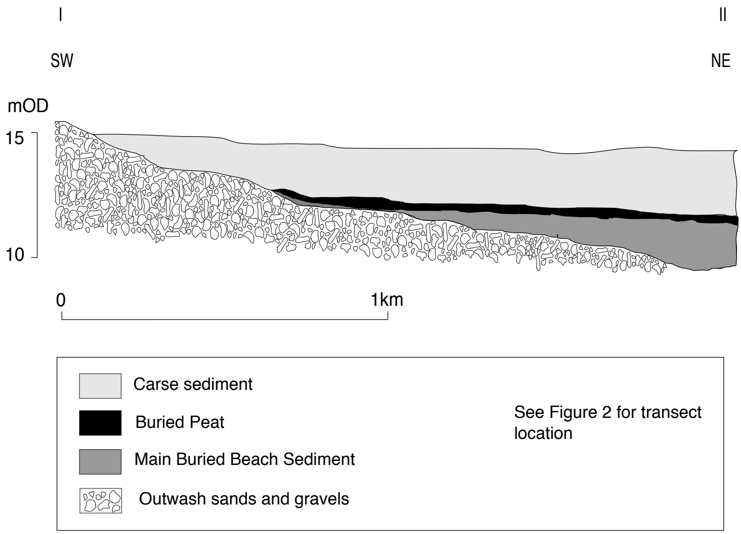

Figure 6 Schematic Stratigraphy of the Western Forth Lowland (after Sissons, Smith and Cullingford 1965).

from the present-day channels of the Forth and Goodie, and presumably in the past peat would have accumulated first, and most successfully, in locations farthest from tidal channels. It is known that the Buried Beach deposits accumulated on both Loch Lomond outwash and older Windermere Interstadial sediments, and it could be that peat growth here was supported by favourable hydrological conditions. The presence of the small lochan at the centre of the Moss, and near the centre of the former peat island, could be because peat compaction in this area is less than in surrounding areas (where carse sediment occurs), and, as a consequence, the peat is more waterlogged.

East Flanders Moss is thus more than a remnant of the peat clearances. Its stratigraphy and morphology reflect complex changes in sea level, sediment accumulation and peat growth. The length and detail of this record demonstrate the unique character of this fine lowland peat moss.

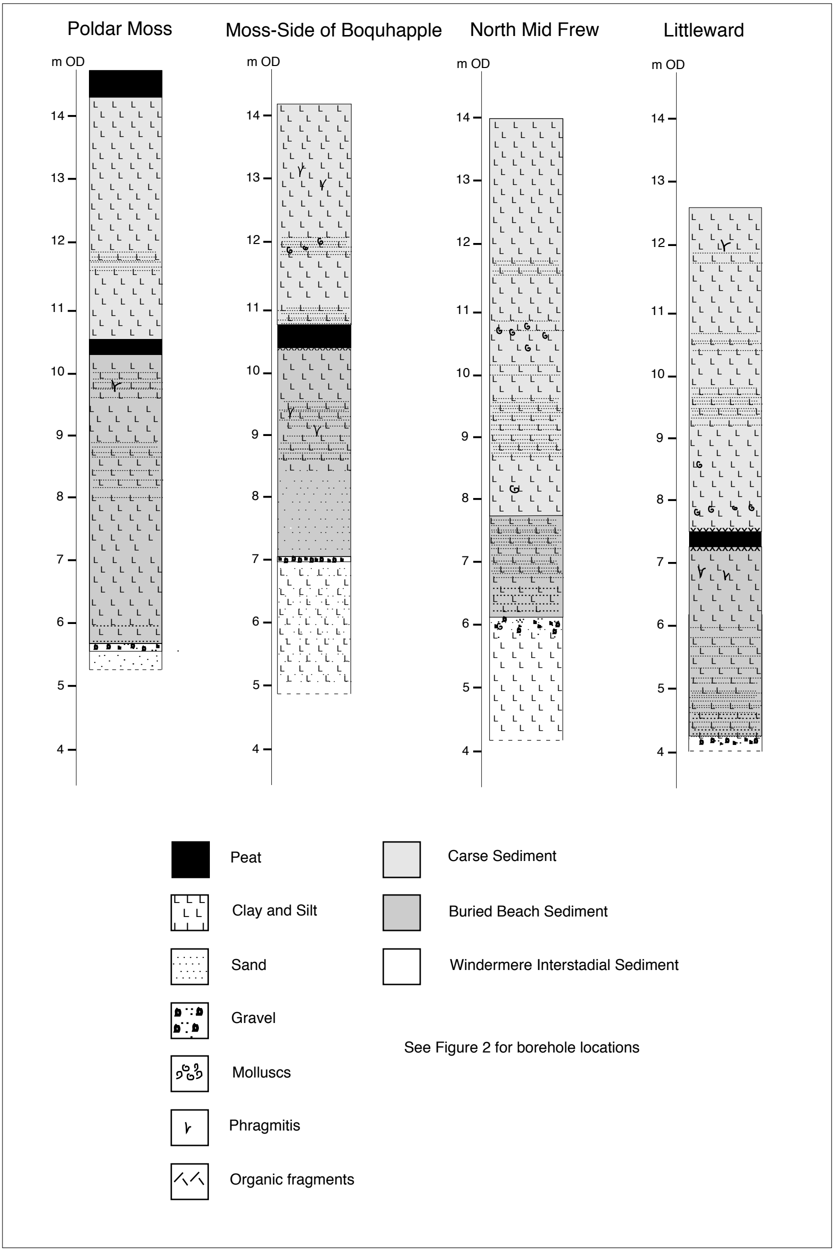

Figure 7 Selected Borehole Stratigraphy, Western Forth Lowland.

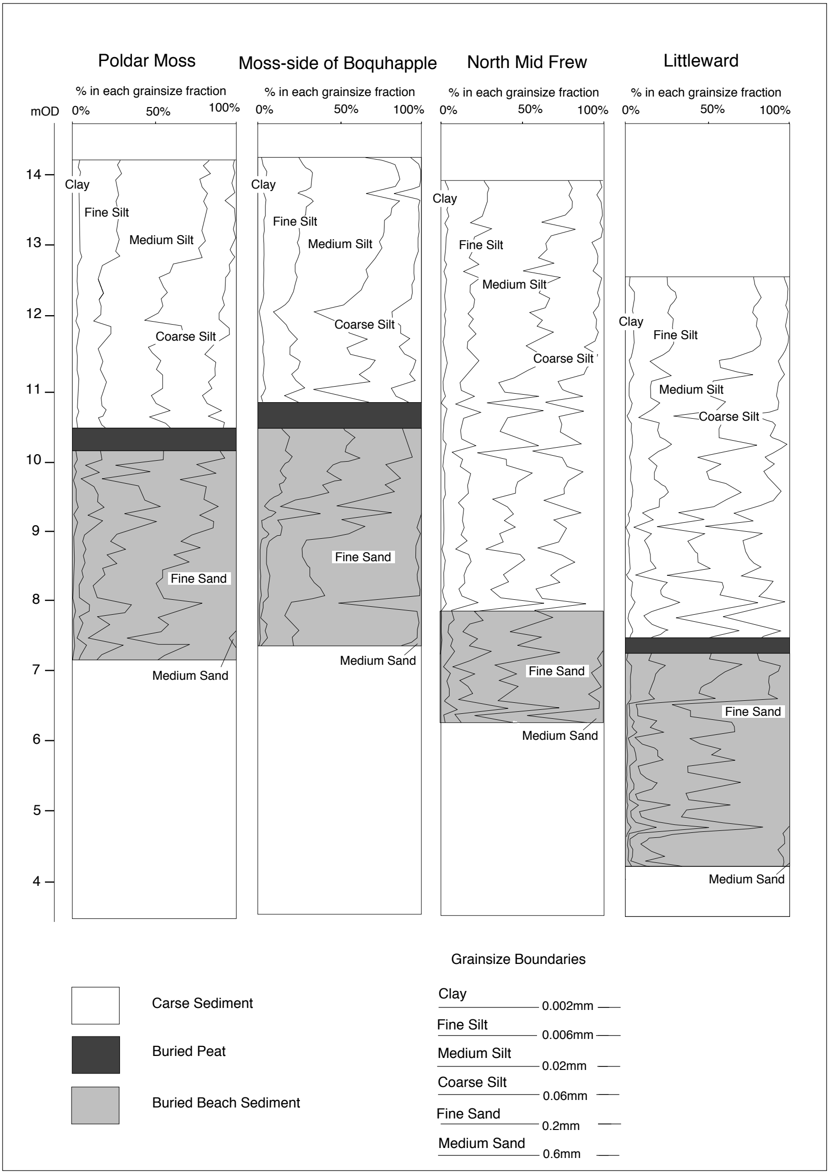

Figure 8 Particle Size Variation in the Sediments of the Western Forth Lowlands.

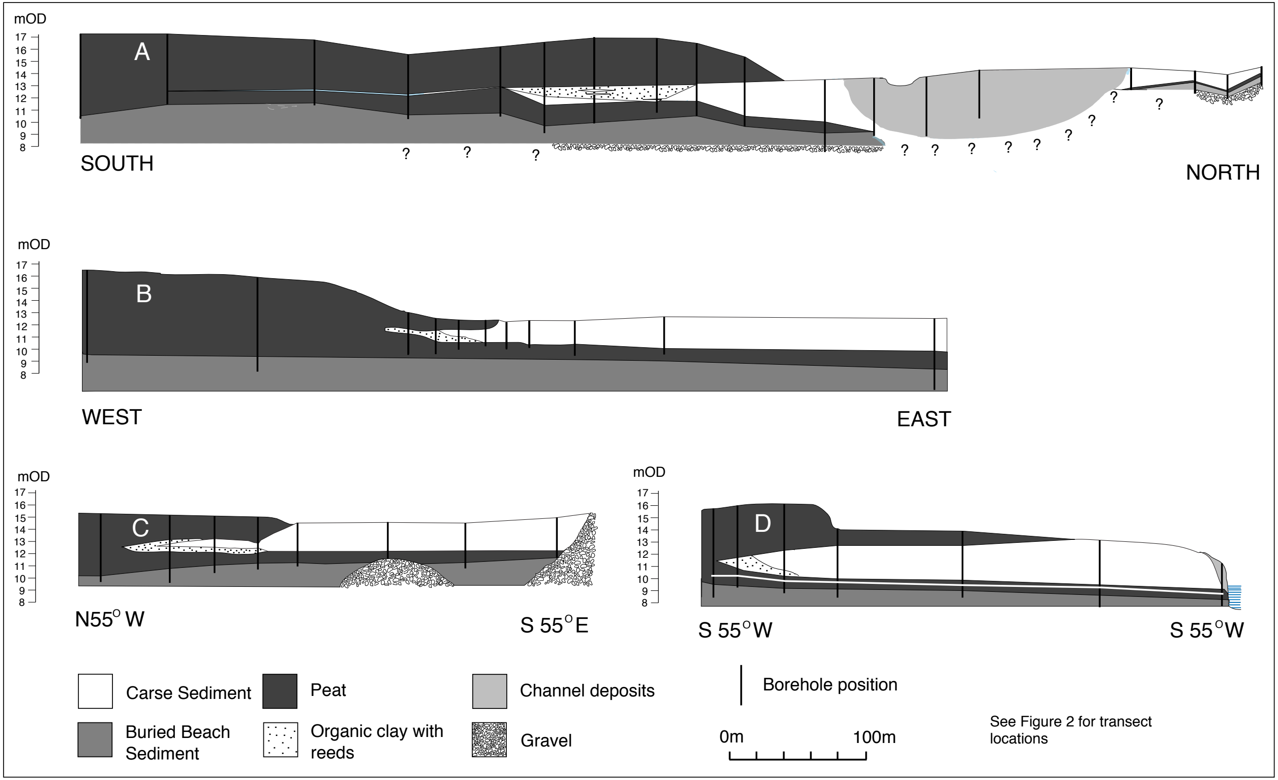

Figure 9 Carse Wedge Stratigraphy, East and West Flanders Moss.

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