Working towards the development of Eco-hydrological Guidelines for Blanket Bog and Associated Habitat – A Scoping Study

PROJECT CODE: ENV6003515

Annexe 1: Reference Sites

August 2020

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Report to:

Environment Agency,
in partnership with Natural England, Natural Resources Wales, Scottish Environment Protection Agency and Scottish Natural Heritage

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1.1 Waun Fignen Felen, Powys

1.1.1 Site context

The area labelled 'Waun Fignen Felen' by the Ordnance Survey is an irregular trough centred at about SN 821 183, within a valleyhead col flanked to the north-east and south-west by quite steeply rising hills. Its highest point is between 490 and 500 m aOD. On the south-west side, the land rises to 558 m aOD at Carreg Goch, on the north-east side to more than 700 m aOD at Fan Hir. At its north-western end, the trough drains south-westwards, joining with drainage from the slopes of Cefn Rhudd (a south-westward projecting spur of Fan Hir), whereas the south-eastern end comes close upon the valleyhead of the south-eastward draining Afon Haffes, but appears to be separated from this by a shallow ridge.

The specific area of peatland considered here is located at the south-eastern end of the trough where there is a shallow peat-filled basin (centre about NGR: SN 823 178) that slopes broadly south-eastwards from about 480 m to 470 m aOD. This appears to be separated from the Afon Haffes valleyhead by a shallow ridge, and much of the drainage within the basin enters sink holes in the vicinity of the peatland. A detailed account of the peat stratigraphy and development of the basin has been provided by Smith & Cloutman (1988), whilst recently Low (2017) has considered the hydrogeology of the site and has installed some installed some dipwells for hydrological monitoring. Results from these have not been seen. Both of these authors use the name Waun Fignen Felen just to refer to the south-eastern basin. Here, except where stated, this name is applied to the entire peatland trough and the label 'south-eastern basin' can be equated with the 'Waun Fignen Felen' of the other authors.

1.1.2 Geological features

Waun Fignen Felen is located towards the north-west corner of BGS England & Wales Sheet 231 (Merthyr Tydfil) for which there is a (rather thin) supporting *Memoir* (Barclay, Taylor & Thomas, 1988). It is situated on the northern limb of the broad anticlinal basin of the South Wales Coalfield, which here dips roughly south and south-westwards, with reported dips of 13° and 15° (Barclay *et al.*, 1988). The peatland area is located almost entirely over a rockhead of the karstic Dowlais Limestone, which here forms a band some 0.5–0.6 km wide. Down-dip (south and south-westwards) this is replaced by a sequence of younger Dinantian limestones (Penderyn Oolite Member > Oxwich Head Limestone > Oystermouth Formation) and thence Namurian strata. Of these latter, the oldest, which constitutes the basal unit of Namurian rocks, is the Twrch Sandstone Formation (formerly the 'Basal Grit'). This adjoins the limestones and forms the upper slopes of Carreg Goch. Up-dip Dowlais Limestone is replaced at rockhead by the Dinantian Cwmyniscoy Mudstone Formation (which corresponds broadly with the Lower Limestone Shale of Barclay *et al.* (1988), and which here corresponds very roughly with the headwaters of Afon Haffes), and thence by Devonian strata of increasing age. Thus the main hill south-west of the site (Carreg Goch) is formed of Dinantian limestone capped by Namurian sandstone (*i.e.* younger rocks form the higher slopes), whilst Fan Hir to the north-east is composed mainly of a sequence of 'Old Red Sandstone' strata in which older strata occupy the higher locations.

There are numerous NNE–SSW oriented faults in the general area, one of which (downthrown to the ESE) crosses the Dowlais Limestone at or near the north-west edge of the south-eastern basin of Waun Fignen Felen. A number of sink holes ('shake holes') are mapped by OS in the vicinity of the site, and BGS has mapped a long band of 'Foundered Strata' along the (mostly lower) north-eastern slope of Carreg Goch and, further south, of Castell y Geifr (and also along faults on the Twrch Sandstone moorland). 'Foundering' (the wholesale collapse of rock strata due, very often, to the dissolution of underlying strata) is associated both with the Dinantian deposits and the Twrch

Sandstone. Foundered Strata are mapped as enclosing the southern half of the south-eastern basin, which may itself be a solution-collapse feature.

Peat has been mapped by BGS along the length of the Waun Fignen Felen trough as a deposit of varying width, widening into the drainage valleys at the north-western end, and into the south-eastern basin. Over a substantial part of the trough it is flanked, and probably underlain, by Devensian Till, but at the south-east basin Till has been mapped only along the north-east flank of the Peat. Dowlais Limestone is mapped at outcrop on the slopes north-west and south-east of this basin, whilst Foundered Strata encircle much of its southern end. It is not possible to determine from the BGS mapping to what extent the peat of the basin is underlain by Till, but Low (2017) concluded that the basin is likely to be lined with a low-permeability Till, sufficient to maintain a water table perched over the limestone. It is not clear how well this fits with the record of "light-brown clayey sand with some gravel" beneath the peat by Smith & Cloutman (1988), but these authors also stated that "beneath the bog itself boulder clay is encountered".

A further, rather curious, narrow and elongate strip of peat has been mapped on the Carreg Goch hillslope south of the south-east basin, falling from about 530 m aOD to just below 490 m aOD and not associated with mapped Till. As mapped by BGS, this peat unit effectively replaces the Foundered Strata that are otherwise extensive on this hillslope, and the relationship between the two units is not certain. The lower end of this strip of peat is separated, as mapped, from the peat of the south-east basin by about 100 m. Low (2017) has reported that this peat deposit is associated with a small, but largely permanent, stream that rises from the limestone (and has apparently caused significant erosion of the flanking peat). This is thought to provide a surface water source to the basin, though it also raises significant (and unresolved) questions about the height of the 'water table' within the limestone local to the basin, which were not explored by Low (2017) (who thought it likely that the 'phreatic water table' in the underlying limestone was well below, perhaps at least 40 m below, the level of peat in the basin). Apart from this inflow, Low considered that "Around the south-western, western and northern boundaries, any surface runoff from the steep slopes infiltrates into the limestone at the edge of WFF, via a number of sinkholes and associated drainage channels", but did not map either the salient sinkholes or drainage channels. A clear topographical map of the site, identifying such features, would be beneficial.

1.1.3 Surface features and vegetation of the south-eastern basin

Little information has been seen relating to the current topography and drainage of the south-eastern basin, beyond the stratigraphical data provided by Smith & Cloutman (1988) (see below). The main drainage point is said to be near the eastern margin of the south-eastern basin, whence a stream flows through a gorge-like trough into a deep swallow hole. Smith & Cloutman considered that this represents the natural outfall and drainage from the basin. It is joined by a stream which flows north-east across the southern corner of the mire. Low (2017) has subdivided the site into five main units based on "internal watersheds" but has not indicated drainage patterns within them, though some patterns are evident on aerial photographs. Low (2017) also identified an incongruity between the penetration of a stream with considerable erosive power through deep peat at the southern end if the basin, with an implication that its present course may not have been that which occurred when the peat formed. However, none of the sections of Smith & Cloutman crosses through this part of the site, and in the absence of relevant field data it is not possible to make any further assessment.

Parts of the site are heavily eroded. Low (2017) considers that "The main erosion feature within the site appears to be relatively flat, extensive, bare or partly vegetated, peat surfaces... These drain to shallow-sided water courses which are often partially filled with deposited peat, and often partly or fully vegetated", whilst "There are relatively few narrow, steep-sided gulleys, of the sort seen extensively elsewhere in Wales… with the main example being the gulley which hosts the small stream which enters the site from its southern boundary." The extent of erosion constrains any assessment of its likely former topography. "It is clear however that central parts of the peatland stand above peripheral areas, and that drainage of the peat is to the sides of the peatland, towards sinkholes in the limestone at the edge of the poorly permeable Glacial Till" (Low, 2017). This is also shown in at least some of the sections provided by Smith & Cloutman (1988).

No information has been forthcoming concerning the current vegetation of the site – thus it appears that more is known about the former occurrence of mire species, through Smith & Cloutman's pollen diagrams, than of their current status! Smith & Cloutman (1988) stated that the name of the site can be translated as "the moor of the yellow bog", and suggest this may reflect the former abundance of *Narthecium ossifragum* (as shown in their pollen diagrams).

1.1.4 Peat stratigraphy and mire ontogenesis of the south-eastern basin

The stratigraphy of the south-eastern basin has been examined in detail by Smith & Cloutman (1988) by means of seven intersecting, levelled sections across the mire. These authors have attempted to reconstruct both the development of the mire and the vegetation of its surroundings and some of their cores have been radiocarbon dated. They have helpfully provided stratigraphical details of their main monoliths, so it has been possible to make some independent assessment of their conclusions. However, although they have provided detailed pollen diagrams from their main sampling points, they have not reported the detailed macrofossil composition of the peat beyond some loose, broad and generic categories.

Approximately the western half of the 'south-eastern basin' consists of a shallow late-Devensian lake basin. This was not examined in detail by Smith & Cloutman but shows a characteristic late-Devensian sequence of 'clay-mud' sandwiched between two layers of blue-grey clay (see Section 1.2: Illtyd Pools, Brecon). Their reconstruction suggested that by about 8000 BP this lake basin was occupied by "shallow, reedy open water, outflowing to the east", with some possible evidence of marginal terrestrialisation, and that it was surrounded by wooded and open vegetation on the drier ground. This aquatic environment was followed by a phase of *Phragmites* peat, representing either reedswamp or fen, and with some wood remains. At core G00 (Table 1), more-or-less in the apparent centre of the basin (and the only dated core taken from the main area of basin), the *Phragmites* phase was dated between 9340±110 BP and 6240±90 BP. It is capped by what Smith & Cloutman (1988) term and show as "blanket peat", but for which the generic term 'ombrogenous peat' might be more appropriate. At G00 this was some 3 m thick and these authors suggested that this was initiated at around 5700 BP. On their reconstructed maps, but not in their sections and cores, they indicated that this "blanket peat" had been preceded by a phase of "acid peat", but the distinguishing characteristics of this latter are not made very clear (it may have been a mix of reed peat and *Eriophorum* and *Calluna*). Their reconstructed maps suggest that by 4700 BP "blanket peat" occupied much of the basin proper, but with a possible residual band of swamp, fen and fen woodland along the western margin. However, a thousand years later (about 3700 BP) virtually the whole of the basin proper was mapped as "heathy blanket peat".

Although these authors do not interpret it these terms, their core G00 (Table 1) and the developmental sequence reconstructed for much of the Devensian basin, represents a fairly typical terrestrialisation sequence that has resulted in a 'climax' condition of topogenous bog. On this interpretation, the "acid peat" distinguished by Smith & Cloutman may well represent a transient phase of 'transition mire' deposited as a progenitor to ombrotrophication and followed by ombrogenous deposits. Perhaps the main feature of note is the rather asymmetric distribution of minerotrophic deposits within the basin, particularly that reed peats tend to be higher in the profile towards the western side of the basin and gradually lower and peter out eastwards. One explanation for this could be that the western side of the basin received telluric inflows from Carreg Goch, as surface run-off or groundwater outflows, a view compatible with the linear downslope strip of peat that occurs on this hillside, just above the south-east basin. This possibility raises important questions about water supply to the original and, to some extent perhaps, the present

Table 1. Stratigraphical records of Smith & Cloutman (1988) from their sampling points G00 and E188S.

Site G00 Four cores taken with the large-diameter hand-operated peat sampler described by Smith et al. (1988).

0–10 cm: modern root mat.

10–290 cm: fibrous blanket peat with frequent *Calluna*; *Eriophorum* between 56–100 and 250–270 cm. 270–290 cm less fibrous. 290–304 cm: grading into reedswamp peat with red wood. *Menyanthes* seed and ?*Betula* twig at 296 cm.

304–400 cm: *Phragmites* peat becoming compacted below 370 cm. 1.5 cm diameter ?*Betula* twigs at 332–338 cm.

400–498 cm: firm, laminated reed peat with much *Phragmites*. Small twigs and some moss below 472 cm.

496–498 cm particularly mossy and with apparent charcoal.

498–512 cm: warm-brown fine detritus mud.

> 512 cm: grey clay.

Site E188S Monoliths taken from peat hag on southeast margin of bog.

0–10 cm: modern root mat.

10–140 cm: dark-brown, fibrous blanket peat containing some *Eriophorum* and *Calluna*. Much charcoal above 24 cm with charred leaves and stems of *Calluna* and *Erica tetralix*. *Sphagnum* leaves and *E. tetralix* seeds in sample at 40 cm. Samples between 48 and 56 cm with charred ericaceous remains. Some mineral material from 136–147 cm.

140–147 cm: black (mor-like) peat with much charcoal and some mineral particles, becoming blacker and greasier towards the base.

147 cm: thin layer of buff-coloured sand above large stones

basin. If some form of telluric inflow along the western side is assumed, the disposition of at least the later (upper) layers of the *Phragmites* peat can be interpreted economically as indicative of a 'Seepage Percolation Basin' (WETMEC 13), probably in this context 'Seepage Percolation Quag' (WETMEC 13b) (in Wheeler, Shaw & Tanner, 2009). Such surfaces are often readily prone to ombrotrophication, *via* a phase of 'transition mire'.

On the eastern side of their site, Smith & Cloutman (1988) found evidence for thinner peats, originating not so much from telmatic deposits but mostly from mor humus. The date of inception of these peats is variable, with dates given of between about 8000 and <4500 BP. It appears that by about 5700 BP "blanket peat" development was widespread around the eastern side of the basin, together with some residual "heath on mor". This was typically associated with charcoal remains in the peat deposit and provides a clear example of paludification, probably induced, as Smith & Cloutman suggested, by cultural activities in the vicinity of the lake basin. The stratigraphy of their sample E188S (Table 1) illustrates this type of development, and at this sample site the base of the ombrogenous deposit was dated at >5430±80 BP (the base of the underlying mor was given as 6210±90 BP).

The interface between the paludifying peats of the basin slopes and the terrestrialising peats of the basin is not well represented by Smith and Cloutman's cores, but the two available cores (E1N and E13N), both taken from near the edge of the Devensian basin, are relevant. E13N consisted of around 218 cm depth of "blanket peat" over a thin layer of "fibrous reedswamp peat" (about 40 cm) and "muddy peat with charcoal" (about 5 cm). The basal substratum (below 260 cm bgl) was given as "light-brown clayey sand with some gravel". E1N consisted of some 15 cm of "blanket peat" (probably much truncated by erosion) grading down into what appears to have been a weakly minerotrophic peat with much *Eriophorum* (about 20 cm) and then into some 25 cm thickness of unambiguously minerotrophic peat and then mud. Carbon-14 dates for the initiation of ombrogenous peat in these two cores were given as 4820±80 BP (E1N) and 5230±80 BP (E13N).

Smith & Cloutman (1988) suggested that "It seems likely that the acid peat moved westwards across the basin from an earlier point of initiation", but their evidence for this seems just to be "that in transects A and C the reedswamp peats rise westwards". Low (2017) repeated their view: "Accumulation of (fen) peat was initiated in a closed basin, followed by ombrogenous peat spreading from the east".

However, the stated, dated base of ombrogenous peat at the eastern margin (E1N and E13N – the only relevant cores available) seems to be more than 1000 years *younger* than that nearer the centre (G00) of the Devensian hollow [Smith & Cloutman (1988) themselves recognised that when a widespread cover of "acid peat" was evident in the basin, reedswamp persisted along the eastern margin at E1N and E13N, which they attributed to the proximity of the main drainage outfall from the basin].

It is important to appreciate that only one dated core is available from the main area of the Devensian basin. It is also important to recognise that, despite the common phraseology, peat does not normally 'spread' laterally (as does inwashed sediment) but it is essentially an autochthonous deposit (*i.e.* it accumulates where it forms). Potentially peat-forming plants may, of course, be able to spread laterally providing that the receptor conditions adjoining them are appropriate for their growth. Thus any 'spread' of peat, in whatever direction, and its concomitant character, is likely to depend on the conditions where it is initiated, which may themselves be time-gradational. Thus it is quite possible to have peat that has developed by terrestrialisation closely abutting upon peat that has developed by paludification without necessarily implying *any* ontogenic connection between the two. It is suggested that this is likely to have been the case at Waun Fignen Felin, with ombrogenous peat arising independently within the main basin and on the surrounding slopes. Of course, ongoing accumulation may bring the two seral sequences together spatially, and lead to some interaction between them.

Within the basin itself, on the evidence currently available, it is not at all clear that ombrogenous peat has necessarily spread from the east. This could, of course, be the case but if, as suggested above, the progenitor surface was a 'Seepage Percolation Quag' (WETMEC 13b of Wheeler et al, 2009), acidification may well have occurred first in the wetter more 'quaggy' conditions away from the basin margins. It is nonetheless accepted that minerotrophic conditions may well have persisted for longest near the location of any telluric inflows along the western margin. Penetration of these into the basin is likely gradually to have been constrained by an accumulating 'plug' of ombrogenous peat, thereby further stimulating the development of this, and diverting any former inflows along the western margin.

1.1.5 Implications for mire characterisation and typology

Smith & Cloutman (1988) referred to all of the surface peat associated with the south-eastern basin as "blanket peat". It is not known to what extent this reflects terminological lassitude or whether they did not find it possible to make any sensible distinction between different samples of ombrogenous peat across the site. As they do not provide details on macrofossil composition beyond those illustrated here in Table 1, it is not possible to make an independent assessment of this from their data. They did, however, point out (in the caption to their Figure 3) that "the extensive eroded peat area to the west (now virtually devoid of vegetation)… is a basin with sediments dating back to the Late-Devensian period." This broad co-extensivity between the limits of the Devensian basin and susceptibility to severe erosion of the peat suggests that the ombrogenous peat that had formed within the Devensian basin had significantly different hydraulic characteristics to the less eroded peats of the marginal slopes.

Low (2017), subject to some caveats, appears to have considered that the system represents a small 'raised bog'; that "it is clear… that central parts of the peatland stand above peripheral areas"; and that, before erosion, "it seems likely that, at least partially, groundwater within the peat formed a mound, with quasi-radial drainage to sinkholes into the limestone at the edge of the poorly permeable superficial deposits". Some of the sections of Smith & Cloutman (1988) also show clear evidence for a 'central' mound of peat, falling away to lower margins, which may equate with the 'lagg' of a raised bog. This is not the case in all sections however, and some do not obviously support the proposition "that central parts of the peatland stand above peripheral areas". Several possible explanations could be given for this, including interaction between the ombrogenous peats of the basin and those of its immediate surroundings, and also that the presence of sink holes around the margins of parts of the basin may have obviated the formation of more significant and continuous lagg drainage. [It may be noted that at the more lowland Illytd Pools (see Section 1.2), there is no evidence for a well-developed lagg on one side of the ombrogenous unit on Traeth Mawr.] It may also be noted that the main drainage point suggested by Smith & Cloutman appears to be at the junction between the deeper peat of the basin proper and the shallower peat of the slopes, so that the outflow stream from this may represent a lagg stream embedded between the two main peat units. Some of these uncertainties could probably be resolved by more detailed topographical survey and mapping.

Overall, the south-eastern basin of Waun Fignen Felen appears to resolve into two main peatland components: an area of slightly sloping 'raised bog' (or 'topogenous bog') developed by terrestrialisation within a shallow late-Devensian lake basin, largely surrounded (particularly on the eastern side) by deposits of a thinner hill peat, developed by paludification. In places the two deposits are juxtaposed and seem to coalesce and may interact, but, notwithstanding the lack of detailed macrofossil information, they appear to represent distinct units. In general, the area of topogenous bog appears to have been considerably more susceptible to erosion than the bog peat of the flanking gentle slopes. The topogenous bog is apparently unusual in that radial flow of mire water from the peat mound seems to be swallowed by sink holes rather than contribute to a well-defined lagg stream (at least in parts of the site (Low, 2017). The character and development of peat in the Waun Fignen Felen trough north-west of the south-eastern basin is not known.

1.2 Illtyd Pools, Brecon

At only about 325 m aOD and amidst agricultural land, Illtyd Pools (NGR: SN 96 25) may scarcely qualify as 'upland', but the site is included here as a counterpart to Waun Fignen Felen (about 475 m aOD). It was examined by the Mires Research Group (British Ecological Society) in 1984 (Meade & Wheeler, 1990).

1.2.1 Site context

Illtyd Pools forms part of an open common some 8.5 km south-west of Brecon. The site occupies a shallow basin embedded in the top of a narrow ridge (Mynydd Illtyd). The surface of most of the basin is slightly below 330 m aOD, whilst the enclosing ground rises variably up to a maximum of about 360 m aOD. There are two main areas of peatland, occupying separate basins and with separate drainage streams – Traeth Mawr is drained by Camlais Fach and Traeth Bach by Camlais Fawr. The western part (almost half) of Traeth Bach has been drained, but the residual area remains very wet. Both sites were considerably grazed when examined in 1984.

1.2.2 Geological features

The site is encompassed by BGS England & Wales Sheet 213 (Brecon). There is no published *Memoir* for this area, but information in the *Memoir* for adjoining sheet 232 (Abergavenny) (Barclay, 1989) is relevant. The bedrock beneath the site and much of the surrounding area has been mapped as St Maughan's Formation. This is a thick, early Devonian deposit described as "Interbedded purple, brown and green sandstones and red mudstones with intraformational conglomerates containing calcrete clasts". A series of sandstone bands are mapped at outcrop more than 1 km north-west of the site, but the rockhead beneath the site has all been mapped as 'Interbedded Argillaceous Rocks and [Subequal/Subordinate] Sandstone'. Much of the area around the peat basins is mapped as Till (of unknown characteristics) and this may underlie the peat is at least part of the basins. However, as mapped, Till is absent along the southern side of Traeth Mawr and around the eastern end of Traeth Bach, and in these locations St Maughan's Formation abuts directly upon peat. Springs are mapped at the junction between St Maughan's rock and peat at the eastern end of Traeth Bach and, although not mapped, groundwater outflows also occur in parts of Traeth Mawr. Much of the drained western part of Traeth Bach was not mapped as peat by BGS and, as this area was not examined by the Mires Research Group, its status is not known to us.

1.2.3 Vegetation and surface features

The vegetation of the two mire basins is strikingly different. Traeth Bach is essentially occupied by a form of wet fen, mostly referable to S27, but separated from the land margins by a very wet, quaking soakway, at least around the northern and eastern margins. This basin is not very relevant to the more upland mires considered here.

By contrast, some of the slopes around Traeth Mawr, especially along the eastern side, show evidence of seepage, and drain into a wet, often unconsolidated, soakway system around the east and south sides of the mire. This is also fed directly by springs in at least two places. pH values measured in the soakway in 1984 were consistently high (> 7) and a locally-unusual feature of its vegetation is the occurrence of a patch of *Cladium mariscus. Carex lasiocarpa* and *Sparganium minimum* are also notable features of this rich fen vegetation. On its north-east side, the marginal soakway is flanked by, and partly penetrates into, an apparent 'ombrotrophic' surface, dominated mostly by *Eriophorum vaginatum* and *Molinia* and with some *Sphagnum* (mostly *S. capillifolium*). Some of this is relatively intact; other parts, especially in the south-eastern area, were described as "degenerate" and consisted of an apparently eroding surface, with pools and gullies of various sizes and levels. Meade & Wheeler (1990) considered that these were at least partly a consequence of trampling by livestock, and that they provided a route for the ingress of base-rich water into parts of the former 'ombrotrophic' area.

1.2.4 Peat stratigraphy and mire ontogenesis

In the work reported by Meade & Wheeler (1990), levelled stratigraphical sections [P.D. Hulme] showed that both Traeth Bach and Traeth Mawr occupied shallow lake basins (about 3.5 m and 5 m deep, respectively), largely lined by clay and partly filled by clays and gyttja. Evidence of basal laminated clays was found only in the section across Traeth Mawr[1], but occurred in all of its cores except at the very margins. The lake deposits were succeeded by fen peat and, in the north-western section of Traeth Mawr, by a shallow accumulation of 'ombrotrophic' peat, which consisted mostly of *Eriophorum* peat with a shallow cap of recent *Sphagnum* peat. Layers of friable peat were interpreted as evidence for past peat cuttings, and there was surface evidence for this as numerous apparent peat pits. The 'ombrotrophic' surface rose gradually north-westwards from the soakway to the land margin and was essentially followed by the water table. Water pH of the 'ombrogenous' surface was 4.1, but increased gradually to 5.6 at 1.5 m depth. Hydraulic conductivity of the 'ombrogenous' peat was estimated (using seepage tubes) at 0.2 $\mu m\ s^{-1}$ in an unlined cavity below about 12 cm depth in two separate locations [O.M. Bragg].

[1] It is possible that the cores in Traeth Bach were insufficiently deep to encounter this deposit.

The clays and gyttja found in the basins have resulted from inwash and the accumulation of plant remains. “The laminated and pink mottled clay, the lower gyttja and the upper clay form a characteristic late-glacial (Late Devensian) sequence and probably accumulated from around 14000 BP (years before present) to about 10000 BP” [P.D. Hulme]. The subsequent accumulation of gyttja over the upper clay layer, probably represents early Flandrian temperature rise and was followed by a terrestrialisation sequence of fen and bog. The past occurrence of peat cutting, of uncertain extent and depth, constrains any interpretation of the development of ombrogenous conditions, but it appears that the ‘ombrotrophication’ was distributed eccentrically within the basin, constrained south-westwards by a base-rich soakway which drained groundwater outflow north-west along the south-western side of the basin. The present ombrogenous surface is configured as gradually rising north-westwards to the land margin, where it merges with the drier ground. It is not known whether this deposit was once more obviously convex than is now the case.

1.2.5 Implications for mire characterisation and typology

The Traeth Mawr basin provides a context in which a small raised bog might be expected to form, but the present ombrogenous surface appears neither to be convex nor to have had a lagg along much of its dryland margin (except in the trivial sense that minerotrophic conditions of some sort must occur at the meeting point between the bog and drier ground). The groundwater-fed soakway along the south-western margin could be regarded as some sort of ‘lagg’, but it appears essentially to be a groundwater-fed feature, receiving outflows from a Maughan Formation aquifer, which has constrained the development of an ombrotrophic surface beyond its present limits. Other outflows within this groundwater-fed basin may also have constrained the development of ombrogenous conditions elsewhere, and the overall impression is that ‘ombrotrophication’ has been restricted to those circumstances and locations where groundwater outflows were least significant within the basin. Ombrogenous deposits of this type occur in a number of peatland basins.

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2 The Southern Pennines

2.1 Introduction

2.1.1 Location, climate & topographic context

The southern Pennines form the southern part of the spine of hills the runs that length of northern England, reaching from Leek in the south-west, to Sheffield in the east, and Keighley in the north. The Buxton meteorological station (307 m aOD) in the south-west of the area recorded annual rainfall of 1329 mm during the period 1981–2010, with 171 days of rainfall, and maximum and minimum temperatures of 5.2°C and 0.5°C respectively for January, and 18.9°C and 11°C respectively for July. However, annual precipitation may reach approximately 1500 mm on the hilltops.

The uplands of the southern Pennines reach an altitude of 633 m aOD on Kinder Scout and are characterised by a series of undulating plateaus and rounded summits with gently sloping broad ridges running down from the tops, dissected by deep, steep-sided valleys.

2.1.2 Geology & soils

The rocks of the southern Pennines are predominantly Carboniferous in age, and the hills and plateaus that support blanket mire landscapes are characterised by alternating sequences of gritstone, sandstone, mudstone, shale grit, and siltstone of the Millstone Grit Group. Some sandstones of the Lower Coal Measures Group are exposed in the east of the area.

Peat (as mapped by the British Geological Survey) covers some 300 km^2 of the southern Pennine uplands, particularly on the higher plateaus, summits and ridges, but also forming extensive sheets of peat running down the gently sloping flanks of these hills. The BGS also mapped small areas of Head (periglacial down-wash material) beneath the scarp slopes of some of the larger hills and plateaus, and Alluvium in the river valleys between the major hills and plateaus, but Till is not generally mapped in this region. Where it has been measured, bog peat across the region is generally between one and three metres thick, though locally it can be up to 6 m deep.

The Soil Survey of England and Wales (1983) mapped the peatland areas of the southern Pennines as Winter Hill soils, described as “Thick very acid raw peat soils, perennially wet, hagged and eroded in places”. These are generally fringed by Belmont soils which are “Coarse, loamy, very acid upland soils over rock with a wet peaty surface horizon and thin iron pan”; and/or Wilcocks 1 soils: “Slowly permeable seasonally waterlogged fine loamy and fine loamy over clayey upland soils with a peaty surface horizon”.

2.1.3 Bog vegetation

The contemporary plant communities of the southern Pennines blanket mires are mostly composed of two *NVC* types:

M19 *Calluna vulgaris–Eriophorum vaginatum* blanket mire, and

M20 *Eriophorum vaginatum* blanket mire.

M20 is often the more common community and is typically overwhelmingly dominated by *Eriophorum vaginatum*. Drier edges of gullies often support vegetation that has more in common with dry heath, being characterised by *Vaccinium myrtillus* and *Empetrum nigrum*.

Other plant communities are associated with southern Pennine blanket mires, either present on flushed ground embedded within the blanket mires, or fringing them, or on areas of eroded peat. These include:

H9 *Calluna vulgaris–Deschampsia flexuosa* heath

U6 *Juncus squarrosus–Festuca ovina* grassland
M6 *Carex echinata–Sphagnum recurvum/auriculatum* mire
M21 *Narthecium ossifragum–Sphagnum papillosum* valley mire
M23 *Juncus effusus/acutiflorus–Galium palustre* rush pasture
M25 *Molinia caerulea–Potentilla erecta* mire

2.1.4 Blanket bog research

Early blanket bog research from the 1940s to the 1990s focused mainly on investigations into peat stratigraphy and pollen analysis. Later work from the 1990s involved studies of vegetation types and the extent of erosion; while more recent research has been dominated by hydrological research and monitoring, usually in conjunction with restoration work.

The main areas of blanket bog research in the southern Pennines are listed below:

1) Early studies found evidence of two distinct types of bog, some sites having affinities to lowland raised bogs, with deep peat forming in shallow depressions on upland plateaus (Leash Fen, Ringinglow Bog, Lucas Moss). However, the majority of blanket bog sites are situated on gently sloping convex plateau summits and broad ridges, with generally shallower peat (though sometimes smaller areas of deeper peat have accumulated in small depressions within the wider blanket mire).
2) Dates of initiation of bog peat, which vary from site to site.
3) Descriptions of three broad peat types – ‘basal’, ‘lower peat’, and ‘upper peat’ and their relationship to likely surface conditions in the past.
4) Identification of bands of *Sphagnum* macrofossils typically found interspersed with bands of *Calluna* and *Eriophorum* macrofossils in the upper peat layer, and investigation of their likely relation to periods of wetter and drier climate.
5) Examination of the differences between current bog vegetation types and those likely to have been present in the past, including the loss of *Sphagnum imbricatum* and the almost total loss of most *Sphagnum* more recently, and possible reasons for these changes.
6) Identification of the types of blanket bog erosion, possible reasons for these, and likely dates for onset of erosion.
7) The presence of localised pool and hummock patterning on blanket bog and evidence for its formation.
8) Hagging and gullying as the predominant surface patterning of most southern Pennine blanket bogs.
9) Investigation into controls upon natural re-vegetation of erosion gullies in blanket peat.
10) More recently, blanket bog restoration has been seen as a priority, and monitoring data from these has been used for several research projects.

2.1.5 Site accounts

A wealth of research has been undertaken across the southern Pennines over many decades. Information from some of these investigations is presented below, particularly where researchers reported combinations of the following data types: vegetation type, peat depth, peat stratigraphy, hydrological data, and hydrochemical data.

- Ringinglow Bog – vegetation, peat depths, peat stratigraphy, water levels, water pH.
- Leash Fen, Lucas Moss & Totley Moss – vegetation, peat depths, peat stratigraphy.
- Kinder Scout & Bleaklow region – vegetation, peat depths, peat stratigraphy.
- Keighley Moor – vegetation, peat depths, peat stratigraphy.
- Monitoring of landscape scale blanket bog restoration projects.

2.1.6 Blanket bog 'types'

Two forms of blanket bog have been recognised in the southern Pennines by various researchers:

1) 'Water-collecting' areas with a more-or-less concave topography of the underlying mineral surface.

2) 'Water-shedding' areas with slightly convex mineral ground topography.

The first type typically occupies shallow hollows or flatter sections of the plateaus, hill tops, and broad ridges (*e.g.* Ringinglow Bog, Leash Fen, Lucas Moss); in the southern Pennines these seem to be quite localised. The second type is much more widespread and appears to be typical of most of the broad, gently sloping hill summits, plateaus, and ridges above about 350 m aOD in the southern Pennines.

It is likely that at least some parts of the 'water-collecting' bog sites could be considered to be examples of 'Domed Ombrogenous Surfaces' (WETMEC 1 of Wheeler et al., 2009).

2.2 Ringinglow Bog

Ringinglow Bog is situated at NGR SK26100 83600, about 8 km to the south-west of Sheffield city centre.

Studies undertaken by Conway in the 1940s provided a large volume of data for this site, including peat depths, surface contours, underlying mineral ground contours, watercourse locations, peat stratigraphy, and dating using pollen analysis and pollen zones (Conway, 1947 & 1949).

2.2.1 Topographical & geological context

A prominent ridge marked by the Millstone Grit escarpment of Stanage Edge (458 m aOD) runs roughly north-west to south-east, separating the Derwent Valley in the west from a series of smaller valleys running eastward toward Sheffield. At its south-eastern end the ridge broadens to form a gently sloping plateau covering approximately 4 km^2. Bog peat has formed within a broad, shallow, slightly-sloping depression that covers much of this area, bounded by slopes rising towards Stanedge Pole (about 440 m aOD) in the north-west, Rud Hill (425 m aOD) in the north-east, Ox Stones (421 m aOD) in the south-east, and Stanage Edge (457 m aOD) in the south-west. The bog surface lies between 400 and 420 m aOD, and gently slopes predominantly to the south. Three streams drain the bog, forming the headwaters of Burbage Brook, and these exit the bog at its southern edge. The road from Sheffield to Hathersage more-or-less marks the south-eastern boundary of the bog, although shallow peat continues beyond it to the south.

The western part of the bog is named White Path Moss; the eastern part was informally named Ringinglow Bog by Conway as part of her research.

British Geological Survey (Sheet E100; 2012) mapping shows that Ringinglow Bog and White Path Moss are underlain by layers of gritstone, sandstone, and siltstone of the Millstone Grit Group, including areas of Redmires Flags and Chatsworth Grit. Towards the north-eastern edge of the bog there are mudstone, siltstone and sandstones of the Lower Coal Measures Group.

2.2.2 Vegetation and surface features

Conway described the vegetation of the bog as consisting of two large 'flushes' [implying water movement, not base-enrichment] drained by the two streams which meet at the single main drainage outlet of the bog. *Eriophorum vaginatum, E. angustifolium*, and *Deschampsia flexuosa* are the most important species of the flush vegetation, except for a small area close to the bog margin at Friar's Ridge, which is dominated by *Juncus effusus*. Between and around the flush areas are regions that are slightly less wet, which are characterized by abundant *Calluna vulgaris*. *Sphagnum* was described as occasional at best, and typically comprised *Sphagnum fallax*.

There are recent anecdotal records for *Andromeda polifolia* near the eastern end of the site, in vegetation that when sampled informally clearly had closest affinity to M18 community (R. Tratt, pers. comm. 2019). This species is extremely uncommon in the southern Pennines.

2.2.3 Hydrology and hydrochemistry

Most of the site is ombrotrophic, but at the north-western edge there is some influence of telluric water from the mineral ground of Friar's Ridge, which forms the northern edge of the bog. Possibly around 1800, ditches were cut at the eastern end of the bog, and these drain eastward into the headwaters of the Limb Brook. A large ditch has also been cut across White Path Moss to Burbage Brook, though this has recently been blocked.

Using simple peat pits, Conway concluded that the water table was never more than 30 cm below ground surface even in the best drained areas, and in the wettest parts it was above 'soil-level' for large parts of the year.

Conway found that pH values of the peat at about 10 cm depth ranged from pH 3.1 to pH 4.1, with a mean value of pH 3.7 for the wettest area and pH 3.5 for areas with abundant *Calluna*. The values were higher in summer than in winter.

2.2.4 Peat infill and characteristics

Conway (1947) carried out extensive peat depth surveys, surface levelling, and examined peat stratigraphy in great detail at several locations across Ringinglow Bog. The bog slopes most steeply in the south-west, close to the edge of Burbage Brook, becoming very gradual further to the east, north-east, and to the west (on White Path Moss). Peat generally deepened quite rapidly from its margins, reaching a maximum depth of just over 6 m near the south-eastern corner, but with a large part of the centre of the bog being more than 4 m deep. Conway noted that the material beneath the peat was usually a mixture of sand and clay, probably derived from weathered Millstone Grit and shales. She stated that:

> "There is an entire lack of evidence of any original lake basin or basins, and this idea is borne out by the character of the mineral matter brought up by the borer. Though it showed a general south-westwards slope, the underlying ground was characterized by one well-defined trough in the general direction of the present-day East Brook, and probably another one, much less well-defined, running roughly north-eastwards, and draining into Burbage Brook perhaps where the present smaller eastern tributary joins it. It is clear also that the deepest peat occurs in the regions at the heads of these two troughs in the original surface."

In the deepest peat area (the eastern shallow hollow), the basal peat was described by Conway as amorphous, lacking *Sphagnum* leaves microscopically. Passing upwards there was a gradual transition to highly humified *Sphagnum* peat, with a progressive freshening towards the upper surface (mainly the upper 2 m), with frequent *Eriophorum* remains and scattered *Calluna*. Notably, the uppermost 5 cm or so lacked *Sphagnum* remains, being replaced by *Eriophorum* peat. Preserved Sphagna were mainly the large 'bog-building' species, including some *Sphagnum imbricatum*, though this was absent above 50 cm depth. Between 350–150 cm depth *Sphagnum imbricatum* and *Sphagnum capillifolium* were abundant, changing to abundant *Sphagnum imbricatum* and *Sphagnum magellanicum* from 150–50 cm. Above 50 cm *Sphagnum papillosum* was frequent.

To the west side of this deep peat area, the peat was generally much shallower (1–4 m deep), and there was often a basal layer of wood peat; in some places much of the profile was wood peat with only a little bog peat above it, especially closer to Burbage Brook. Most wood peat remains were of alder and birch. As well as wood peat, the profile also showed increased quantities of *Calluna* macrofossils and less *Sphagnum* than the central deep peat area, and there was no evidence of *Sphagnum imbricatum*.

Peat coring in the shallow peat on the gentle north-west facing slope south of the road showed the peat there to be approximately 1.2 m deep. Macrofossil analysis showed ericoid dominance with little *Sphagnum*, but more prominent *Sphagnum* remains were present about 10 cm below the surface.

2.2.5 Mire ontogenesis

Conway concluded that mire development was probably initiated by paludification of poorly drained ground, rather than terrestrialisation of a lake basin. Regarding her investigation in the area of deepest peat, she suggested the following:

> "The onset of 'Atlantic' climatic conditions allowed the formation of a damp grassy flush in hollow ground surrounded by a rapidly disappearing 'Boreal' forest. Flush vegetation remained until… the natural successional changes, probably involving increased soil acidities, allowed the development of bog vegetation, with *Calluna*, *Sphagnum* and Cyperaceae as the main components."

Pollen analysis suggested that peat formation began at the Boreal–Atlantic boundary (quoted by Conway as about 8200 BP, but more recent revisions to this date indicate that this would have been around 7500 BP).

Conway considered that the basal layer of wood peat that was found closer to Burbage Brook implied that a long-lasting dense woodland occupied the better-drained region around the headwaters of Burbage Brook while, further afield, a more open damp heath / woodland type occupied the regions with less effective drainage, in which bog conditions more quickly established themselves at the expense of trees and scrub.

Pollen analysis of the shallower (about 3 m) peat close to Burbage Brook showed peat formation began at approximately the same time as in the deeper peat profile. The upper layers showed very slow growth compared with the deep peat area, suggesting that this part of the bog became drier in this period, possibly because of the natural drainage channels cutting further into the bog and improving drainage. Conway summarised the likely developmental trajectory of this shallower western area of bog as follows:

> [Initially there was] "a dense alder–birch woodland whose trees were probably rooted in the mineral soil, and… the ground flora… consisted mainly of grasses, rushes and ferns. [This was followed by] a change… which caused the opening out of the woodland to allow a much more luxuriant development of grasses. At this stage the trees were probably rooted in peat. *Juncus* is fading out, Ericaceae are rather more frequent, and pockets of woodland Sphagna are scattered here and there. At length the woodland succumbs to the bog vegetation which [has] been spreading gradually westwards from the more poorly drained central region of the bog. Ferns and grass and woodland Sphagna diminish with the retreating woodland, leaving Ericaceae and Cyperaceae as dominants, while bog Sphagna come in a little later in frequent patches, though not as dominants. The… sudden onset of excessively wet conditions cause persistent shallow pools over [this part of the bog] in which *Menyanthes trifoliata* can flourish. Ericoids give way to moisture-tolerating grasses and the whole of [the] lower-lying western part of the bog [becomes] one great flush area. [Following a return to drier conditions] *Calluna* returns to its own, *Eriophorum vaginatum* increases, and *Sphagnum* starts on its progress to ever increasing importance."

Pollen analysis of peat samples from the shallow peat-covered slope on the south-eastern edge of the bog (immediately south-east of the road), confirmed the close relationship of the peat archive with that of the deep basin 400 m to the north-west, i.e. peat accumulation began at about the same time, but with very slow accumulation of peat. Conway considered that these samples were a fair representation of the shallow peats on gentle slopes surrounding the deeper parts of the bog, and that peat formation began at roughly the same time over practically the whole area under consideration.

Possibly around 1800, ditches were cut at the eastern end of the bog, and it is suggested that this was responsible for the replacement of *Sphagnum* by *Eriophorum* and *Calluna* as the dominant species.

2.2.6 Implications for mire characterisation and typology

Conway noted the similarity of Ringinglow Bog to a lowland raised bog:

> "The ground rises rapidly eastwards from Burbage Brook, and in fact the appearance of the ground here strikingly recalls the 'rand' region of a raised bog. The similarity is heightened by the presence on these slopes of frequent *Molinia* tussocks, a species occurring only in one or two small tufts over the whole of the rest of the bog… Growth-rate of the peat has been more rapid, or else started earlier in the moisture collecting hollows of the ground. [The peat profiles] suggest that there is a sense in which the surface of the bog may be said to be convex relative to the underlying ground surface. Again, bog growth at the south-west corner has been limited and retarded by the presence of persistent primary drainage channels, so that on both counts we may see traces of the characteristics of a raised bog."

It would seem that the main areas of deep peat at Ringinglow Bog, and probably White Path Moss too, could be considered to be examples of 'Domed Ombrogenous Surfaces' (WETMEC 1 of Wheeler *et al.*, 2009), which contrasts with the shallower marginal peat on the gentle south-eastern slope near Ox Stones, which appears to have initiated at around the same time, but has probably experienced higher rates of decomposition than the deeper, wetter areas.

2.3 Leash Fen, Lucas Moss & Totley Moss

These three sites are situated within a few km of each other, about 6 km to the west and south-west of Dronfield, in a part of the southernmost Pennines hills known generally as the Eastern Moors. The northern-most, Totley Moss, is about 4 km south of Ringinglow Bog.

Leash Fen: NGR SK 2980 7360; **Lucas Moss**: NGR SK 2655 7680; **Totley Moss**: NGR SK 2765 7875

Hicks (1971) investigated the peat stratigraphy of Leash Fen and Totley Moss, while Lucas Moss was studied as part of two undergraduate research projects at the University of Sheffield (Sharp, 1997; Roebuck, 1997). Some limited hydrological and peat stratigraphic investigations were undertaken for the RSPB and National Trust (Day & Carthew, 2010).

2.3.1 Topographical & geological context

All three sites are situated in broad, shallow depressions on the gently undulating top of a broad ridge that runs roughly north–south, and forms the watershed between the River Derwent to the west, and a series of small valleys draining eastwards to the River Rother and River Don.

Leash Fen

Leash Fen is situated at between about 280 and 290 m aOD, and is roughly 1.4 km^2 in area. Its eastern margin is delimited by a ditched lagg zone, which appears to form the headwaters of both the Blake Brook, which flows to the north-west, and the Blackleach Brook, which flows to the south-west. From the eastern ditch and bog margin, the ground rises up eastwards to a low mineral ridge, before dropping away steeply to the north-east. The northern part of the mire surface slopes gently to the north-west, to the ditched headwaters of the Blake Brook, while the southern-most end slopes down quite sharply into the Blackleach Brook. Its western margin is approximately marked by a deep, straight ditch that flows north-west into Blake Brook (although deep peat extends north-west from the ditch (Day, 2011)), and at its south-eastern end flows into Blackleach Brook. Day & Carthew (2010) mapped a 'watershed' roughly west–east across Leash Fen, suggesting that about two thirds of the site drains to the north-west.

Beneath Leash Fen the British Geological Survey (Sheet E112; 2012) have mapped mudstones, siltstones and sandstones of the Pennine Lower Coal Measures, while the ridge that marks the eastern boundary of the mire is mapped as Greenmoor Rock, a harder sandstone unit of the Lower Coal Measures. No Drift deposits were mapped in this area.

Lucas Moss

Lucas Moss lies at an altitude of between 340 and 350 m aOD, and is situated about 3 km north-west of Leash Fen, immediately to the east of White Edge, a prominent escarpment whose summit (367 m aOD) slopes gently down to the east to form the western edge of the mire. The ground slopes gently up from the northern edge of the bog to a maximum elevation of about 380 m aOD. From the lower margin of the bog, the ground slopes more steeply to the south-east down to Bar Brook, at about 290 m aOD. Beneath Lucas Moss, the bedrock that also comprises White Edge is Crawshaw Sandstone of the Pennine Lower Coal Measures, changing eastwards to mudstones, siltstones and sandstones of the Lower Coal Measures.

Totley Moss

Totley Moss, at an altitude of between 350 and 370 m aOD, is situated at the junction between sandstones of the Millstone Grit and lower Coal Measures, about 2 km north of Lucas Moss. The peat deposit lies in a depression to the west of a ridge known as Flask Edge, whose summit lies at 395 m aOD. To the north the ground rises to the rounded summit of Totley Moor (400 m aOD), and to the west it rises very gently toward the A625 road, which marks the edge of the mire. To the south the ground falls gently, and the Moss is drained by a headwater stream of Bar Brook.

2.3.2 Vegetation and surface features

Leash Fen

The vegetation of Leash Fen was surveyed by Thompson *et al.* (2016), and is dominated by *Calluna vulgaris*, while *Molinia caerulea* is dominant with some *Juncus effusus* in what appears to be a lagg zone along the eastern edge of the site. *Eriophorum vaginatum* is frequent and locally abundant across the bog, and *Sphagnum* species are scattered, though generally more frequent to the south. *Sphagnum fimbriatum* is the most commonly encountered, whilst *Sphagnum subnitens* is quite frequent*, Sphagnum capillifolium, Sphagnum fallax* and *Sphagnum palustre* are occasional, and *Sphagnum papillosum* and *Sphagnum magellanicum* are extremely rare. *Vaccinium oxycoccos* is occasional in very wet areas, and *Empetrum nigrum* is rare.

Lucas Moss

The vegetation of Lucas Moss is dominated by *Calluna vulgaris*, while *Molinia caerulea* is frequent, particularly at the margins (Roebuck, 1997). *Eriophorum vaginatum* and *Eriophorum angustifolium* are frequent and locally dominant, particularly around the margins. *Sphagnum* species were recorded as frequent to locally abundant: *Sphagnum cuspidatum* and *Sphagnum fallax* were the commonest species encountered, but *Sphagnum papillosum* was locally abundant in a particularly wet area, accompanying a small patch of *Vaccinium oxycoccos.*

Notably, in the centre of the bog there are several pools with floating mats of *Sphagnum*.

Totley Moss

No vegetation survey data have been available for Totley Moss, but anecdotal observations suggest that it is dominated by *Calluna vulgaris* on its drier margins, with much *Molinia caerulea* and some *Eriophorum angustifolium* in wetter areas.

2.3.3 Peat infill and characteristics

Leash Fen

Hicks (1971) investigated the stratigraphy of Leash Fen in great detail, examining 27 peat cores along a north-east to south-west transect across the site. The maximum peat depth was approximately 6 m. Underlying the peat, the mineral material showed a transition downwards from pinkish-grey clay, through yellow clay to blue-grey clay, becoming stony at depth. The basal peat of each boring contained wood of *Alnus* or *Betula*, above which was a great depth of *Eriophorum* peat, with intermingled wood remains in the lower parts. In the upper 2 m of the profiles *Sphagnum* remains became prominent, and locally abundant, particularly on flatter ground near the eastern and western margins. At the eastern and western margins of the bog the stratigraphic profile showed an abundance of monocot peat dominated by *Carex* and *Juncus*, grading upwards into *Eriophorum* and *Sphagnum* peat.

The levelled section provided by Hicks showed the deepest peat to be situated over a hollow or shallow trough close to the eastern margin, which could mark a pre-peat drainage channel. The peat then shallowed as both it and the underlying mineral ground sloped gently to the south-west to another shallow hollow or trough.

Lucas Moss

The bog at Lucas Moss is about 550 m across, with a maximum peat depth of approximately 4 m. Aa levelling survey showed that the surface of the bog is slightly domed, with a rise of roughly 3 m north–south, and 0.85 m west–east (Sharp 1997). The 'dome' of the bog appears to be eccentric, i.e. the mire edge is about 1.6 m higher at the northern end, and seems to be independent of the underlying mineral topography.

Sharp (1997) demonstrated that *Sphagnum* macrofossils were abundant in the peat at Lucas Moss throughout much of the peat profile, with the exception of approximately 1.1 to 1.8 m depth, and above 0.4 m depth. No *Sphagnum* macrofossils were present below 3.8 m, or above 0.1 m depth.

Sharp also noted the presence of a more steeply sloping rand-like surface at the mire margin, a lagg zone around the bog, the apparent lack of an acrotelm layer, and that there was little *Sphagnum* growing at the surface.

Totley Moss

Hicks (1971) examined a peat core in the western part of the bog (approximately 4 m maximum depth), which revealed a similar stratigraphy to that at Leash Fen, i.e. clay-rich mineral ground overlain by wood peat, followed by a shallow deposit of monocot peat, then *Eriophorum* peat with frequent *Sphagnum* layers. A second peat core (to about 2.2 m depth) was examined from the eastern end of Totley Moss at a slightly higher elevation than the main bog. This revealed a different stratigraphic succession in which most of the deposit was composed of *Phragmites / Equisetum* peat with abundant wood remains in the basal layers, overlain by *Carex* peat, followed by moss peat composed of *Sphagnum*, *Calliergon*, *Drepanocladus* and *Aulacomnium*, and finally *Calluna* peat with charcoal in the top 12 cm.

2.3.4 Mire ontogenesis

Leash Fen

Hicks (1971) considered the name 'fen' to be a misnomer, since most of the peat deposit is dominated by bog peat of *Eriophorum vaginatum* and *Sphagnum*, and she pointed out that its previous name had been 'Leashfield Moss'. Hicks interpreted the basal wood layer to indicate that:

> "During the early period of peat accumulation this flat and presumably ill-drained col supported an alder/birch woodland. The fact that wood was recorded in every boring suggests that the woodland formed a fairly dense cover… The eastern and western margins of the bog supported communities

> dominated by *Carex* and *Juncus*, but these were overtopped by *Eriophorum* and *Sphagnum* as the bog grew. [The underlying mineral material is interpreted as] a soil developed in situ that has become waterlogged and gleyed with the onset of wetter conditions and the commencement of peat accumulation."

Hicks (1971) reported that a sample from the junction of the peat and the underlying mineral material produced a radiocarbon date of approximately 6300 ± 150 BP. She considered that this placed the commencement of peat growth in the Atlantic period.

Lucas Moss

Based on pollen analysis, Sharp (1997) and Roebuck (1997) both concluded that mire development at Lucas Moss was initiated by paludification of alder–birch carr in a shallow basin, at about 6000 BP.

Totley Moss

Hicks (1971) suggested that the main part of Totley Moss had a similar developmental history to Leash Fen, but that the south-eastern part of the deposit was likely to have been a reedswamp throughout the major part of its development.

'Eastern Moors' Area

From Hicks (1971) studies of Leash Fen, Totley Moss, and several other smaller mires on the Eastern Moors, she concluded that:

> "The results of pollen analysis indicate that on the East Moor peat growth began around the time of the Boreal/Atlantic transition or during the Atlantic period, the time of onset varying in relation to altitude. Over most of the upland the areas in which peat accumulated were shallow, ill-drained depressions supporting, in places, alder/birch woodland… The increased oceanicity of the Atlantic climate caused the initiation of peat growth. It is suggested that during the Boreal period the upland supported a pine/hazel forest that was dense at low altitudes but thinned out on the plateaux tops, where herbaceous plants became more common. By 4000 B.C., before the intrusion of Neolithic man, the East Moor was covered by mixed-oak forest, but the otherwise closed canopy of this forest was broken by areas of damp heath and alder/birch carr, reed swamp and exposed gritstone edges."

2.3.5 Implications for mire characterisation and typology

Although Leash Fen does not have a domed profile, it does appear to have a peat surface that is somewhat independent of the underlying mineral ground, particularly where peat has formed over depressions in the original surface. It also has what appears to be a lagg fen zone along its eastern boundary, and possibly also along its south-western boundary, and the slope of the peat surface down to the western margin of the bog has some resemblance to the rand of a lowland raised bog.

At Lucas Moss, the eccentrically domed profile that is independent of the underlying topography, and the apparent presence of features similar to the rand and lagg of lowland raised mires, suggests that it should be considered to be a form of raised bog rather than blanket bog.

These sites have many similarities to Ringinglow Bog, and consequently they could also be considered as examples of 'Domed Ombrogenous Surfaces' (WETMEC 1 of Wheeler *et al.*, 2009).

The lack of surface elevation data for Totley Moss make it difficult to determine whether its surface profile follows the underlying mineral contours.

2.4 Kinder Scout – Bleaklow Region

Several blanket bog sites across the Kinder Scout plateau and the ridges and cols of Bleaklow were studied by researchers from the 1960s through to the 1990s.

Kinder Scout: NGR SK 085 887

Featherbed Moss: NGR SK 091 921

Alport Moor: NGR SK 112 929

Shelf Moss: NGR SK 090 955

The findings from several of these areas are summarised below. The main aims of these studies were to describe peat depths, peat stratigraphy, pollen profiles, and erosion features; and to better understand the developmental pathways of the southern Pennine blanket bogs, and the reasons for the development of extensive erosion complexes.

2.4.1 Topographical & geological context

Kinder Scout is an undulating peat-covered plateau ranging in altitude from about 580 to 636 m aOD. Featherbed Moss is a prominent but gently sloping 'top', roughly 2.5 km to the north of Kinder Scout, separated from it by the deep Ashop Clough, and has an altitude ranging from about 500 to 544 m aOD. Alport Moor is situated on a shallow col at 515 m aOD, 2 km east-north-east of Featherbed Moss, on a long ridge running south-eastwards from the western end of Bleaklow ridge. Shelf Moss is situated 4 km to the north of Featherbed Moss, in a saddle between the Higher Shelf Stones (621 m aOD) and Bleaklow Head (633 m aOD), forming part of the broad, peat-covered ridge of Bleaklow Hill. Peat is mapped by the British Geological Survey as covering all of these locations, overlying exposures of gritstone, sandstone, and shale grit of the Millstone Grit Group.

2.4.2 Vegetation

Tallis (1964a & c) outlined what he saw as the three major features of southern Pennine blanket bogs: widespread dominance of *Eriophorum vaginatum*, the near absence of *Sphagnum*, and the extensive erosion of the peat blanket. Three lines of anecdotal evidence were also provided:

1) Reports by keepers and shepherds that *Calluna* had decreased at the expense of *Eriophorum vaginatum* during the 20th century.

2) Records from the early 19th century that *Sphagnum* was a prominent part of the upland vegetation of this area.

3) The dramatic decline of *Andromeda polifolia* since about 1860.

Tallis (1964c) described the cover of *Sphagnum* as follows:

> "At present *Sphagnum* species are almost absent from the blanket bog vegetation of the southern Pennines. Apart from local and sporadic occurrences on the higher and more remote moors Sphagna are now confined to flushed areas. Five species only are in any sense widely distributed – *S. recurvum* (not uncommon), *S. fimbriatum* and *S. palustre* (occasional), and S. *papillosum* and *S. rubellum* (rare). By contrast, leaves of *S. acutifolium s.l.*, *S. cuspidatum*, *S. imbricatum*, and *S. magellanicum*, and spores of *S. rubellum* and *S. cuspidatum*, are often prominent in the upper peat. The behaviour of *Sphagnum* is of primary importance in understanding the processes of peat formation and peat erosion in the southern Pennines."

More recent vegetation surveys that have been carried out as precursors to restoration of damaged bog surfaces have demonstrated that Tallis's description remains more-or-less true across large areas of these upland bogs. For example, Eades (2010) found during a pre-restoration survey of part of the Kinder plateau that the bog surface comprised a mixture of bare peat and patches of very species-poor bog vegetation that was dominated by *Eriophorum angustifolium* and *E. vaginatum* on wetter ground, while drier upstanding peat 'haggs' were usually dominated by *Empetrum nigrum*, *Vaccinium myrtillus* and lichens. *Sphagnum* mosses were found to be extremely scarce: along a series of 10-metre wide transects that were 10 km in total length, only 30 patches of *Sphagnum* were found. The commonest species was *Sphagnum fimbriatum*, with occasional patches of *Sphagnum subnitens, S. papillosum, S. capillifolium, S. palustre* and *S. squarrosum*. The patches of *Sphagnum* were typically found within shallow erosion features that have now become at least partially revegetated, predominantly with cotton grasses, and most were associated with shallow gradients and relatively wet ground, often with small shallow pools.

2.4.3 Peat infill and characteristics

Conway (1954) recorded maximum peat depths on the Kinder Scout plateau to about 3 m depth, and slightly deeper peat at Shelf Moss on the Bleaklow ridge to about 4 m depth. Tallis (1964a) recorded peat depth on Kinder Scout of 2.1 m, and 2.6 m of peat was reported at Featherbed Moss (Tallis & Switsur, 1973). At a site on Alport Moor that was studied by Tallis & Livett (1994), peat depths were more recently investigated (Tratt, unpublished data, 2019). That site occupies the broad, gently-sloping nose of a north–south ridge, and a peat depth profile showed the peat surface to follow the underlying contours of the mineral ground (Figure 10), with peat depth generally between about 2 to 2.5 m. The main exception to this was where deeper peat (to 3.2 m) has accumulated in a hollow or trough in the valley of a small stream (Nether Reddale Clough) that drains the ridge top (Tratt, unpublished data, 2019). This finding is reinforced by a study undertaken by Tallis (1964b) at Dean Head Hill, about 8 km to the north of Bleaklow. He found deeper peat deposits beside the headwater streams than on the interfluves between the stream systems, and concluded that these lower gradient areas became waterlogged earlier than the sloping interfluves.

Conway recognized a stratigraphic division of southern Pennine peats into three superimposed layers; these, [modified slightly by Tallis, 1964c] are:

1) A highly humified basal peat, lacking *Sphagnum* but sometimes containing wood, which began to form around 7000 BP.
2.) A humified lower peat, with abundant Ericaceae and Cyperaceae and some *Sphagnum*, which began to form around 5000 BP or earlier.
3) A less compacted and less humified upper peat, with abundant *Sphagnum*, which began to form around 3200 BP.

Tallis (1995; 1998) also described the frequent presence of tree stump layers in southern Pennine blanket peat, suggesting that these were evidence of drier periods.

Tallis (1964c; 1995) reported the presence of 'recurrence surfaces' in the 'upper peat', marked by bands of poorly humified *Sphagnum,* preceded by more highly humified peat layers with much *Calluna* and *Empetrum* pollen. He noted that "Over a given large area, such as Kinder Plateau, the shallower marginal peats show only one or two *Sphagnum* bands, [with up to 7 bands in] the deepest central peats." Tallis also described *Eriophorum vaginatum* as being a conspicuous component of the shallower southern Pennine peats throughout their formation. He considered that it is "very sensitive to changes in the water regime, increasing greatly during periods of dryness and in situations where the drainage has been improved; in addition it is remarkably resistant to changes produced by human interference, in the form of burning, grazing, or atmospheric pollution". Tallis also found abundant charcoal fragments in the top layer of peat, ascribing this to periodic burning episodes, and soot contamination was extensive in the uppermost 2–3 cm of peat – Tallis presumed this to be a direct consequence of recent industrialisation.

Tallis (1964c) considered that *Sphagnum imbricatum* "has always had a localized distribution in the southern Pennines. It is almost invariably confined to the deeper, more central peats, and usually occurs remote from the larger drainage system… *S. imbricatum* … has flourished in the past in the southern Pennines only in a very wet, actively growing, peat blanket." He also stated that "There is little doubt that the disappearance of *S. imbricatum* is bound up with a drying-out of the peat surface, since the peat stratigraphy indicates that this species is very susceptible to a lowering of the water table." By contrast, *Sphagnum acutifolium* (now *S. rubellum / capillifolium*) was shown to be frequent and often abundant in the peat record during drier periods when *S. imbricatum* was reduced or absent. Macroscopic remains of *Sphagnum* in the peat were shown to decrease in frequency throughout the zone of charcoal contamination, and to disappear finally when soot contamination first became obvious.

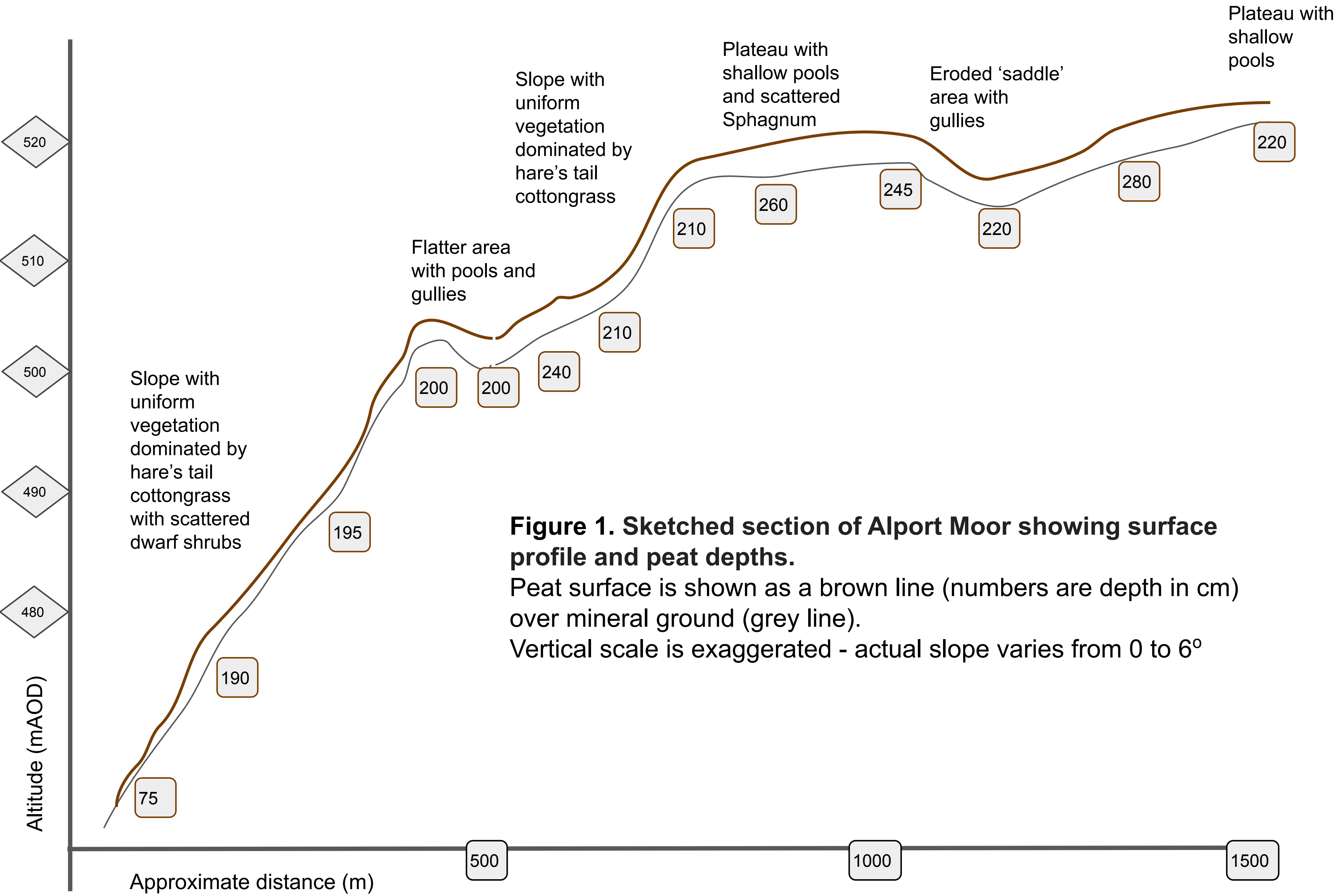

Figure 1. Sketched section of Alport Moor showing surface profile and peat depths.
Peat surface is shown as a brown line (numbers are depth in cm) over mineral ground (grey line).
Vertical scale is exaggerated - actual slope varies from 0 to 6°

At Alport Moor, Tallis & Livett (1994) showed that *Sphagnum* was generally lost from the mire surface by 400–500 years ago, and suggested that, at least at that site, only the disappearance of the moss *Racomitrium lanuginosum* from the hummocks might be attributed to the deleterious effects of air pollution during and after the Industrial Revolution.

Whilst Tallis, Conway and other workers have suggested that *Sphagnum* mosses have in the past been widespread across the blanket bogs of the southern Pennines, many of their peat cores have been taken from the flatter and wetter parts of these bogs where deeper peat deposits have formed, compared with the more sloping sites (*e.g.* Conway, 1954), presumably because better peat preservation in the wetter areas made it easier to identify macrofossils and pollen. A few studies have been made of more sloping peat deposits, but their findings regarding the past presence of *Sphagnum* are more ambiguous. For example, peat macrofossil analyses by Conway on sloping sites on the edge of Ringinglow Bog (Conway, 1947) and the northern slope of Bleaklow (Conway, 1954) showed that *Sphagnum* remains were only a very minor component of the peat. In contrast, on the slopes of Featherbed Moss (Tallis and Switsur, 1973) and Keighley Moor (Blundell *et al.*, 2016) *Sphagnum* was shown to have been a substantial (though variable) component of the peat since about 1200 BC and 550 AD respectively. Thus there is some uncertainty whether the past distribution of *Sphagnum* mosses in the 'climatically marginal' peatlands of the southern Pennines would have included the most steeply sloping areas, or whether widespread and abundant *Sphagnum* cover would have been generally restricted to the deeper, wetter peat of the summits and plateau areas. This has implications for setting realistic objectives for degraded blanket bog, and consideration of the cost-effectiveness of different restoration activities, such as re-introducing *Sphagnum* species.

2.4.4 Surface patterning

Other than peat erosion features, surface patterning has rarely been described from the blanket mires of the southern Pennines. However, it is possible that the extensive surface erosion of these areas could have masked or removed evidence of these features. Tallis (1998) considered that surface patterning on blanket mires appears to be associated with evidence of increased wetness on the bog surface, with excess water unable to drain away from the flattest areas.

Tallis and Livett (1994) and Tallis (1994) studied a small area on the western side of Alport Moor that displays a well-defined hummock–hollow topography with little erosion, though adjacent to more extensive gullying on either side of the broad ridge top. They described both hummocks and hollows as being well-vegetated: *Empetrum nigrum* dominates the hummocks, and *Eriophorum vaginatum* and *E. angustifolium* dominate the hollows. The hummocks were raised 40 to 70 cm above the hollows, Sphagna were absent, but standing water often persisted in the hollows for days or weeks after heavy rain. Lines of preferred water flow after rain (in part underground) were shown to connect the hollows to a gully a few metres to the west.

Tallis (1994) proposed that microtopographic differentiation of the mire surface on Alport Moor into pools, hollows and hummocks resulted from differential rates of peat accumulation locally, with areas of retarded peat accumulation developing gradually into hollows and pools over a time-period of more than 1000 years. The stratigraphic profile from a 15 m section across the study area indicated the existence of four successive stages in the development of the mire surface:

1) a topographically differentiated dry bog vegetation about 2800 BP;
2) this then developed into a wet rather featureless mire surface by about 2200 BP;
3) an extended phase between about 2200 and 750 BP when hummock–hollow differentiation was taking place over the mire surface; and
4) drier bog vegetation since about 750 BP, probably following incision of the main drainage gullies.

Tallis and Livett (1994a) concluded that there was no evidence for the existence of a 'regeneration cycle' of peat accumulation in these profiles.

2.4.5 *Mire ontogenesis*

Tallis (1998) stated that, in a topographically varied landscape such as the southern Pennines:

> "The response to an augmented water balance was generally more immediate at water-collecting sites (flat plateaux, saddle-shaped cols, and local basins) than at water-shedding sites (on sloping ground). Water-collecting sites thus typically showed earlier peat formation than water-shedding sites, and often acted as foci for progressive peat spread to water-shedding sites."

He suggested that before about 8000 BP the climate was too dry for bog formation in the southern Pennines except in suitable water-collecting sites, i.e. open-water infill areas and above wet mineral soil in waterlogged hollows. The onset of the 'Atlantic' period between about 8000 to 7500 BP was considered to have triggered extensive waterlogging of soils on relatively flat ground, and the onset of widespread peat formation. Using pollen diagrams from peat cores at Kinder Scout, Shelf Moss, and Ringinglow Bog, Conway (1954) also concluded that at altitudes over 370 m on areas of little slope and sufficient extent, peat formation began at the Boreal–Atlantic Transition (between about 8000 and 7500 BP). This compares with much later peat initiation in places like the Berwyn of Wales (about 4000 BP). Tallis (1985) suggested that use of the uplands as grazing land for wild game by Mesolithic hunters led to a gradual degeneration of the upland forest, and to a takeover of the flatter ground by peat-forming communities.

At Featherbed Moss, Tallis and Switsur (1973) estimated rates of peat accumulation for the three main peat layers, assuming a peat initiation date there of about 6500 to 7000 BP: basal peat between 2.5 and 3 cm/century; lower peat, about 4 cm/century; upper peat, about 5 cm/century. More generally across the UK peat accumulation rates are estimated at between 1 and 12 cm/century, achieving peat depths up to around 5 m in some locations (Tallis, 1995).

Tallis concluded from his work at Kinder and elsewhere (1964c; 1995) that "The widespread occurrence of recurrence surfaces is probably a result of the relatively dry climate of the southern Pennines even at the highest altitudes. If the normal climate is such that peat formation occurs only at a relatively slow rate, then even a slight increase in rainfall may produce a marked change in the vegetation." Tallis tentatively dated the *Sphagnum* recurrence surfaces to 3200 BP, 2600 BP, 1600 BP and 700 BP, and suggested that a rise to dominance of *Eriophorum vaginatum* after the fourteenth century was a result of human interference. He considered that the "modifications produced resulted in a decline in the frequency of *Sphagnum* in the vegetation, but the almost total absence of *Sphagnum* at the present day can probably be ascribed to the atmospheric pollution of the last 150 years."

More recent work by Tallis (1985) at Featherbed Moss inferred the existence of four long-term climatic regimes during the last 5700 years: a period of relatively dry climate between about 5700 and 2800 BP, when peat growth was slow; a period of wetter climate between 2800 and 1600 BP, during which the peat growth rate increased dramatically; a period from 1600 to 1000 BP when climatic conditions appear to have been most favourable for rapid peat growth; and a period covering the last 1000 years, when peat growth slowed again.

2.4.6 *Erosion features*

Erosion in the southern Pennines is widespread, particularly of the deeper peats, and affects about three-quarters of the total peat area (Tallis, 1985) particularly at sites such as Black Hill, Kinder and Bleaklow (though restoration work has begun to redress this). The proportion of eroded peat is seen to increase with altitude: >90% of the peat above 550 m in the southern Pennines is affected by erosion (Tallis, 1998), and more south-easterly areas may be more severely affected, as both frost and desiccation are likely to act together there.

Peat erosion on blanket mires gives rise to a range of features, including gullies cut into the peat, more deeply incised gullies cut down into the mineral layer, upstanding remnant peat 'haggs', and extensive areas of bare peat (pans or flats) that often have so little peat remaining that the underlying sand and rocks are visible in patches.

Tallis (1985) estimated areas for the different types of eroded peatland in the southern Pennines: gullied peat 1000–2000 ha; marginal peat erosion 50 ha; accidental burns 500–600 ha; footpath erosion 50 ha; soil erosion on hillslopes 750–950 ha. The extent and severity of this peat erosion is probably without parallel elsewhere in Britain, and consequently there has been considerable speculation as to its causes.

Conway (1954) believed that "the prime cause of peat erosion has been the very wet climatic conditions of the past 2500 years, which, at high altitudes, has caused peat growth to be so rapid that mechanical breakdown of the soft peat layers has become inevitable sooner or later".

Tallis (1964c) considered that:

> [the] "phases of wetter conditions indicated by the recurrence surfaces may have been important in determining the pattern of erosion in the southern Pennine blanket peats, producing periodic rejuvenation of gully dissection and also giving rise to a highly unstable peat blanket liable to develop its own drainage system. In recent centuries the pattern of erosion has been modified by intensive human interference, and this has been largely responsible for the characteristic present-day appearance of southern Pennine blanket bogs."

Tallis (1998) described the different types of peat erosion on blanket mires. Bare peat areas typically arise from either superficial / sheet erosion, gully erosion, or marginal erosion. Gully erosion can be split into two categories: Type 1 dissection, on gentle slopes <5°, with intricate branched patterns; and Type 2 dissection on steeper slopes where gullies tend to run parallel to each other.

Type 2 gullies generally conform to the surface contours, following preferred runoff pathways: on concave slopes gullies converge to a point of discharge, whilst on convex slopes the gullies radiate out to separate discharge points. Occasionally individual gullies may be the result of collapse of a peat pipe. The long-term surface runoff required to create Type 2 gullies may have resulted from either/or all of: a) damage to the acrotelm by burning and grazing; b) change to a wetter climate; c) forest clearance on slopes below the bog causing headward incision of streams into the bog margin.

Gully incision rates were proposed by Tallis (1997) for two southern Pennine examples as 6.3 and 5.4 mm/annum. Tallis (1973) and Labadz *et al*. (1991) deduced that the shallower gullies (from 1 to 1.5 m deep) in the southern Pennines were probably no more than 200 years old. Other studies suggest three different time-periods for the initiation of gullying, which may represent successive developmental stages:

1) very slow headward extension of streams into the peat blanket along pre-established lines of weakness (pre-glacial stream channels) beginning about 5000 BP.
2) Accelerated erosion between about 1200–900 BP, possibly caused in part by naturally induced mass movement of the peat blanket (Tallis, 1985).
3) A more rapid extension of gullying between 600 and 250 BP (Tallis, 1995), which may have been related to intensifying grazing and trampling pressures.

The densest networks of open gullies occur on flat or gently sloping surfaces and are thought to have developed from pool systems by the coalescence of adjacent pools (Tallis & Livett, 1994). This requires both an outlet to a watercourse (either a peat pipe, or headward extension of streams), and progressive breakdown of baulks between pools, which could be caused by deer or sheep trampling, wind action, or a wetter climate creating rising water levels in pools (Tallis, 1998).

Tallis (1998) considered that discussions around whether gullying is a natural or anthropogenic feature may have been confused by a failure to separate different forms of peat damage, as these are likely to have different causes, and he concluded that:

1) Gullying of blanket peat is a natural process.
2) Gullying can be initiated by long-term management practices, and by climate change.

3) It is inherently unlikely that gullying is an inevitable termination to peat growth.

2.4.7 Natural revegetation of eroded blanket bog

Crowe *et al*. (2008) studied the natural revegetation of erosion gullies at three blanket bog sites on different parts of Bleaklow. Upper North Grain, (SK 108 938 and altitude 520 m aOD) is a headwater catchment containing both severely eroded gully systems and re-vegetated peat-floored and mineral-floored gullies. Doctor's Gate (SK 095 931) is a headwater catchment at 500 m aOD with re-vegetated narrow V-shaped peat-floored gullies and a notable gully system with extensive revegetation by *Sphagnum* species. Shelf Moss (SK 088958, 580 m aOD) contains large areas of sheet erosion as well as shallow, but wide U-shaped peat-floored gullies with meandering drainage.

The upper peat layer at each site was sampled using a Russian peat corer, and plant spp richness was estimated using 1 m^2 quadrats. It was necessary to distinguish between primary peat (i.e. the remaining pre-erosion peat) and secondary peat (i.e. sediment deposition and peat growth following re-vegetation of the erosion surface). The secondary peat in all cores was confined to the uppermost 20 cm, and the macrofossil records were species-poor.

In their study, Crowe *et al.* (2008) found that all cores showed broadly similar sequences of gully revegetation, mostly initiated by the pioneer coloniser *Eriophorum angustifolium*, though occasionally by *Sphagnum denticulatum* and *Juncus effusus*. The results suggested that *Eriophorum angustifolium* is a key species in the revegetation and regeneration of blanket peat gullies, and in mitigating the effects of further erosion.

Two main trajectories were identified: 1) towards wet *Sphagnum* bog, associated with continuously waterlogged conditions on the gully floor and a nearby source of colonists; 2) to dry heath assemblages characterised by *Vaccinium myrtillus* and *Empetrum nigrum*, typical of establishment on mineral substrate or on peat with a low water table.

Sphagnum recovery (or the lack of) seemed to depend more on the availability of spore-banks than on levels of sulphur pollution in the peat (from past industrial pollution), and the authors considered that accelerated climate change is likely to become the greatest challenge in re-establishing *Sphagnum*-rich blanket bog. This could have major implications for the sustainability of existing wet bog communities, and for the colonisation of remaining bare peat areas, particularly as the climate of the Southern Pennines is already considered to be marginal for the growth of blanket peat (Tallis, 1995).

Crowe *et al.* (2008) found that the geomorphological context significantly influences the pattern and trajectory of revegetation of eroded blanket bog, such that in narrow steep gullies re-vegetation tends to propagate upstream from local blockages, whilst in broad shallow gullies re-vegetation may propagate in either direction from the initial location.

2.4.8 Implications for mire characterisation and typology

The information examined for the Kinder–Bleaklow area suggests that blanket bogs that have developed on these undulating plateaus and broad summit hills and ridges are mostly examples of 'water-shedding' sites with slightly convex and sloping mineral ground topography. They are likely to have developed by way of paludification of high, gently sloping ground during periods of wetter climatic conditions. Within this it is possible for there to be localized elements of 'Domed Ombrogenous Surfaces' (WETMEC 1 of Wheeler *et al.*, 2009) where small 'water-collecting' hollows are embedded in the ridges and plateaus.

The climatically marginal situation of the southern Pennines, with respect to conditions suited to the development of peat deposits, has clear implications for the future characteristics of many of these bog sites. The oscillations that were identified by Tallis and other researchers (*e.g.* Tallis, 1964c) between conditions in which the peatland vegetation supported an abundance of

Sphagnum, and conditions where *Sphagnum* was virtually absent, which they ascribed to wetter and drier climatic periods, indicates that during the current warmer climatic phase the widespread abundance of *Sphagnum* on sloping blanket bog may be an unlikely situation on all but the gentlest of slopes.

2.5 Keighley Moor

A palaeo-ecological study was made of blanket peat at Keighley Moor, at the northern tip of the southern Pennines (NGR SD 982 395), with the aim of examining how the existing vegetation relates to the mire vegetation present at the site in previous centuries or millenia (Blundell & Holden, 2014; Blundell *et al.*, 2016). These studies were unusual in that they gathered a range of linked datasets: peat depth; peat stratigraphy; degree of peat humification: abundance of macrofossils and testate amoebae; and radiocarbon dates for different peat depths. One of the aims of the studies was to use these data as proxy measures in order to reconstruct water table levels throughout the development of the bog.

2.5.1 Topographical & geological context

Keighley Moor is situated approximately 7 km west of the town of Keighley and provides much of the catchment for Keighley Moor Reservoir. The reservoir lies at about 370 m aOD, and from the reservoir the ground rises steadily to the west for about 1 km to a ridge marked by the summit of Wolf Stones (443 m aOD) at its south-western end, and by Maw Stones (about 430 m aOD) at its north-eastern end. The study site comprises an area with variable cover of blanket peat on the slope west of the reservoir, with the main region of deeper peat between 400 and 435 m aOD, mostly situated on the interfluve between Crumber Hill Dike to the south, and an unnamed stream to the north.

The British Geological Survey has mapped Woodhouse Grit and Woodhouse Flags sandstone of the Millstone Grit Group beneath the site, and a patchy covering of Peat on the slopes between the reservoir and the ridge top.

2.5.2 Vegetation and management

Blundell & Holden (2014) reported that the vegetation of the peatland areas at Keighley Moor is dominated by *Calluna vulgaris,* with frequent *Eriophorum vaginatum, E. angustifolium*, and *Vaccinium myrtillus*, the latter being found particularly on shallower peat areas. Whilst *Sphagnum* mosses are typically rare, wetter areas (such as gully bottoms) support patches of *Sphagnum fallax,* with less frequent *S. capillifolium, S. fimbriatum* and *S. cuspidatum.* Blundell & Holden considered this to represent an ‘inactive’ bog in terms of peat accumulation. The study area is managed for grouse and sheep grazing, and there is no artificial drainage, though natural watercourses drain from west to east, down to the reservoir.

2.5.3 Hydrology

Seven years of hydrological monitoring was undertaken by Blundell *et al.* (2016) between 2008 and 2015 across the study site. This demonstrated the overriding importance of rainfall and evapotranspiration as controls on the modern water table. Water is received at the study site primarily from rainfall, but also indirectly as runoff or throughflow from the slope above the site, which extends to the watershed roughly 500 m to the west, and is itself covered with either peat or thin, probably acidic soils. The below-ground water table was found to be within 5 cm of the surface for 66% of the year, and within 10 cm of the surface for 87% of the year (Blundell & Holden, 2014).

2.5.4 Peat infill and characteristics

A peat depth survey showed that almost half of the reservoir catchment had peat greater than 0.6 m deep, but only about 5% of the catchment had peat greater than 1.8 m deep. Three distinct areas of deeper peat were found, and the largest of these (Area 2) had a maximum depth of 3.72 m. The mean depth for these three areas ranged from 1.5 to 1.85 m (Blundell & Holden, 2014).

Peat cores generally showed a transition from mineral ground to peat within 20 to 30 cm of the base of the profiles. Birch or alder wood and charcoal remains were also found at the base in areas of deep peat, demonstrating the presence of some tree cover prior to peat accumulation (Blundell & Holden, 2014). The deepest area of peat in Area 2 had remains of *Phragmites* at the base of the peat.

A more detailed peat stratigraphy survey was undertaken (Blundell & Holden, 2014), following a 300 m east–west transect along the central deep peat lobe (Area 1), which had a gradient of about 1 in 12. The peat was mostly about 2 m deep, with a maximum of 2.94 m depth at the lower eastern end, and there were some remains of birch wood peat and much charcoal at the base. Above the wood peat were sedge and ericaceous remains, followed by abundant *Sphagnum* and *Eriophorum* peat in the upper 1 m, but the uppermost 0.1 m or so showed a change to amorphous peat with charcoal, sedge roots & ericaceous roots, demonstrating a sudden recent loss of *Sphagnum*.

Detailed macrofossil analysis of one of the deeper cores showed a cyclical variation in relative abundance of *Sphagnum* species and *Eriophorum vaginatum* between 1.55 and 0.08 m depth (Blundell & Holden, 2014). *Sphagnum magellanicum* and *Sphagnum* section *Acutifolia* were generally dominant, although *Sphagnum papillosum* became dominant between 0.14 and 0.08 m depth (dated to between 1830 and 1910).

2.5.5 Mire ontogenesis

Blundell & Holden (2014) considered that the three areas of deep peat deposits were likely to have been the initial foci of peat accumulation. Peat initiation probably occurred over previously wet mineral ground mainly via paludification, and the presence of charcoal remains suggests that there may have been a link between peat initiation and clearance of woodland cover by humans. However, evidence of *Phragmites* remains in the deepest area of peat suggests that there may also have been an aquatic phase of peat initiation in small hollows within the slope.

Chronology provided by radiocarbon dating gives peat initiation in Area 1 (at 2.85 m depth) to have been around 4020 to 3850 BP, although the deeper peat deposit in Area 2 could be older. Blundell & Holden (2014) considered this date to be coherent with the transition to wetter conditions found in other peat-based records across northern Europe. Accumulation rates were inferred to range from 42 years cm^{-1} near the base, to 8 years cm^{-1} at depths of 42–73cm.

The first establishment of *Sphagnum* was dated to about 1400 BP, which is coincident with the Dark Age period, and may have been a response to the onset of wetter climatic conditions at that time. There is evidence of burning throughout the history of this site, but *Sphagnum* always returned until about 120 years ago (i.e. post-dating the start of the Industrial Revolution), and today *Sphagnum* is very rare at the surface. Severe wildfires were recorded in 1918 and in the 1940s, and controlled burning for grouse management has been a feature of the area since the 1870s.

Blundell & Holden (2014) concluded that the past recent presence of *Sphagnum* at the site provides support for restoration plans "to revive *Sphagnum* moss in a focused way, encouraging it primarily in the areas of deeper peat accumulation where it has been demonstrated historically as being relatively resilient".

2.5.6 *Implications for mire characterisation and typology*

The development by paludification of relatively shallow bog peat on a steady slope means that it is probably best to describe this site as an example of 'Hill Bog'. While there are some deeper deposits with limited evidence of terrestrialisation of a shallow hollow in the slope, it seems unlikely that these can be considered to be examples of 'Domed Ombrogenous Surfaces'.

2.6 Blanket bog restoration in the southern Pennines

The blanket peatlands of the southern Pennines are distinctive for the degree and intensity of physical erosion that they have suffered in the last millennium (Alderson *et al*., 2019). In addition to the loss of habitat for upland fauna and flora, there has been recent recognition that while intact peatlands are significant carbon sinks, erosion can lead to the transformation of these areas from carbon stores to carbon sources. This has led to a series of landscape scale blanket bog restoration projects across the southern Pennines, with a particular focus on areas of extensive peat erosion, including Kinder Scout, Bleaklow, Black Hill, and Holme Moss.

2.6.1 *Restoration aims*

Peatland restoration typically aims to restore hydrological function, vegetation cover, and 'active' peat forming vegetation (Anderson *et al.,* 2009). More recently these aims have been described in terms of the enhancement of a range of peatland 'ecosystem services', such as provision of clean water, carbon storage, runoff regulation, and biodiversity (Bonn et al., 2016).

2.6.2 *Restoration techniques*

Restoration of damaged blanket mires can comprise a range of measures, including blocking grips and small gullies with wood, plastic or peat dams; slowing water flow in larger gullies with the use of rock piles or coir rolls; stabilising bare peat surfaces; and introducing bog species such as *Sphagnum* mosses and *Eriophorum angustifolium* (Adamson & Gardner, 2004). Where extensive areas of bare peat are present, stabilisation of the surface to prevent further peat loss is usually a priority, and for this the use of grass as a nurse crop has been successfully trialled in the southern Pennines. This involves aerial spraying of a mixture of lime, fertiliser and grass seed over bare peat areas, followed by spreading a layer of mulch, usually of cut heather brash to provide initial protection for the growing seedlings – this is known as the Lime–Seed–Fertiliser–Mulch (LSFM) approach (Alderson *et al.*, 2019). Gully sides and hagg slopes are often stabilised using geotextile membranes or coir matts, with heather mulch. Gully floors and peat flats may be plug-planted with *Eriophorum angustifolium*, and *Sphagnum* species.

In some areas of sloping peatland *Molinia caerulea* has become dominant, particularly where frequent burning and heavy grazing has been undertaken for some time. Ongoing research is investigating the effect of cutting to reduce its dominance and plug-planting *Sphagnum* to increase diversity of the sward.

2.6.3 *Monitoring methods*

Because appropriate hydrological functioning within blanket mire is usually a prerequisite for the enhancement of ecosystem services, a more detailed understanding of the hydrology of blanket mires has been developed in order to inform the restoration effort (Low, 2017; Allott *et al.*, 2009). Water table monitoring using dipwells is a typical component of a peatland restoration monitoring programme (Allott *et al.*, 2009), combined with assessment of vegetation recovery using quadrat and transect sampling, and measurements of hydrological and hydrochemical parameters such as runoff, dissolved organic carbon (DOC) and particulate organic carbon (POC) (Alderson *et al.*, 2019).

2.6.4 Outcomes of blanket bog restoration

Peatland restoration is a slow process and requires long-term monitoring in order to assess its success or otherwise. With the aim of better understanding ecosystem responses to the LSFM treatment in a severely eroded peatland system, a recent study by Alderson *et al*. (2019) synthesised the best available current data from five restoration areas in the southern Pennines over a 15-year period. They examined changes to vegetation cover and the presence of indicator species; water table levels; runoff patterns; and changes in water quality, with the aim of evaluating the integrated impact of standard restoration approaches.

Alderson *et al.* (2019) found that three parameters responded very rapidly to restoration – percentage vegetation cover, runoff, and sediment yield:

- There was almost 100% reduction in bare peat within 6 years of initial treatment.
- Particulate organic carbon (POC) flux fell by an order of magnitude within the first two years of re-vegetation.
- There was an increase in the lag time and a decrease in peak storm discharge recorded in flood hydrographs at the hillslope scale.

Despite the rapid development of vegetation cover on bare peat, changes to the cover of typical bog plant indicator species and overall species richness of bog indicator species (as opposed to the nurse crop species) occurred much more slowly.

The changes to POC flux and runoff are almost certainly linked to an increase in surface roughness from early colonisation of non-moorland species (i.e. the grass nurse crop), which has the effects of both slowing the flow of surface-generated runoff, and creating conditions where absolute flow velocity is reduced and as a consequence suspended POC is re-deposited.

An overall trend was observed post-restoration for a small but ongoing rise in water table relative to control sites, possibly related to changes in soil hydrological function. No significant change to dissolved organic carbon (DOC) was measured five years after restoration.

The patterns of ecosystem change shown by Alderson *et al.* (2019) suggest that three key timescales define the response of the peatland system to LSFM restoration:

1) At timescales of about 2 years – rapid change in surface conditions through establishment of nurse crop cover.

2) At timescales of about a decade – establishment of blanket bog indicator species richness to levels close to intact peatland sites (as characterised by Common Standards Monitoring Guidance for blanket bogs (JNCC, 2009)).

3) At timescales in excess of a decade – ongoing recovery of subsurface hydrological function, which causes water tables to continue to rise at these slower rates.

The data presented by Alderson *et al.* (2019) demonstrated that not all the restoration aims can be achieved over short timescales, but they identified key benchmarks that may lead to progressive improvements. From their work, they concluded that the establishment of vegetation cover and the increase in surface roughness as a consequence, are key to rapidly reducing particulate carbon loss and attenuating stormflow. Whilst biodiversity gradually improves due to the return of native species, and hydrological function slowly recovers, Alderson *et al.* (2019) suggested that within short project timescales the primary focus of monitoring for peatland restoration using the LSFM approach should be measurement of vegetation establishment, rather than trying to demonstrate high and functioning water table (Holden *et al.,* 2011), and the presence of keystone peatland species.

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3 North York Moors

3.1 Background

In aggregate, the North York Moors contain a rich resource of wetland sites. Moorland[1] of some form covers more than 500 km^2 of the area, and the higher upland areas are dominated by 'moorland', often on lower permeability-rocks. Much of the main area of moorland (the 'North York Moors proper') occupies a broad ridge between the Tabular Hills to the south and Eskdale to the north. This plunges irregularly eastwards from more than 400 m aOD in the area of the Bilsdale Moors to around 200 m aOD at Jugger Howe Moor. Over much of this area, the main rocks at outcrop are those of the erstwhile 'Estuarine' or 'Deltaic Series', now mostly encompassed within the Long Nab Member of the Scalby Formation, and of the older Cloughton Formation. These are separated, often along the higher parts of the watershed, by Moor Grit (Scalby Formation) and Scarborough Formation rocks.

The higher parts in particular can support extensive tracts of blanket bog peat of variable depth, though often less than about 2 m (Elgee, 1912) and with large areas less than 0.5 m deep (Simmons & Cundill, 1974). Some of the deeper examples have formerly served as local turbaries. Both altitude and rainfall are relatively low (mostly <400 m aOD and around 1000 mm annual rainfall), which makes this area one of the driest in Britain for blanket peat development. It thus provides an example of the development of blanket mire habitats at the periphery of their climatic range.

A number of the areas of peatland have been examined by palaeoecologists, but primarily from the perspective of establishing the vegetation history of the Moors rather than the ontogenesis of the mires. Thus stratigraphical cores presented in published work usually relate just to those used for palaeoecological analyses and are usually from the deepest parts of the peatlands. Further cores, showing the topography of the basins etc. are either not available or, in some cases, provided just in Ph.D. theses (*e.g.* Atherden, 1972) rather than in subsequent publications.

Some valuable insights into the character of the peat areas of the North York Moors have been provided by Elgee (1912). Although this work was early, written before many insights about wetlands were made by others, and also rather discursive, it contains some valuable observations. Elgee had been influenced by the (then) recent work of German telmatologists showing that in their *Hochmoore* (raised bogs) the peat was generally convex, with the centre of the bog higher than that at the edges. He specifically considered the extent to which this was the case in some of the mires he examined in the North York Moors. He was sceptical of the early (and now disproven) view that the observed convexity of some bogs was due to the capillary capacity of peat and *Sphagnum*:

> "Why this lifting capacity should act more effectively at the centre than at the edges is not clear unless it is that at this place there is more water to absorb. Bog Mosses undoubtedly retain large quantities of water on the slopes of mountains, hills and moors; but it is not at all clear how this is going to elevate a bog in the centre. If we examine the mosses and Bogs on the Eastern Moorlands, we invariably find that those occurring in sloping hollows near springs, those on slopes and flats such as Bluewath Loose How etc., and particularly those that occur in slacks, are very little higher at the centre than at the edges; and if we ask what feature these bogs have in common and in what way they differ from those bogs which are convex, we find it to be a fact that there always is and always must have been an escape for superfluous water. Whereas in the case of May Moss and Harwood Dale Moss, though lateral escapes now exist for the superfluous drainage, a careful consideration of the ground has led me to the conclusion that during the earlier stages of their history such escapes either did not

[1] 'Moorland' is a term often used in the UK to describe open habitat that is generally characterised by acidic, low nutrient, often waterlogged soils, supporting a mixture of acidic grassland, heathland (both dry and wet), and bog vegetation. Moors are generally upland, but some lowland areas are also called 'moors'.

exist or were sporadic. It is clear that where the effluent drainage is equal to or greater than the inflow there can be no convexity of surface."

3.2 Occurrence of upland mires

Perhaps the best indication of the distribution of blanket bog peat is provided by the distribution of Winter Hill Association soils (raw oligofibrous peat soils) (Jarvis *et al.,* 1984). Apart from an outlying area at Arden Great Moor, these are mostly aligned in a west–east orientation along the spine of the watershed, especially between the R. Seph north of Helmsley, from Bilsdale Moors eastwards to the vicinity of Egton High Moor. They are generally flanked by soils referred to the Onecote (cambic stagnohumic gley) and Maw (humus-iron pan stagnopodsol) Associations, which are also very poorly drained and often waterlogged for long periods.

BGS surveyors have mapped much less peat in the North York Moors than is indicated by the distribution of Winter Hill soils. Two main areas of what may be construed as blanket bog peat have been mapped by BGS, and presumably represent deeper deposits that form part of, and are within, the more extensive areas of Winter Hill soils. One (outlying) deposit of 'BGS-mapped peat' occupies the plateau of Arden Great Moor, in the Hambleton Hills at the western end of the Moors, just below 400 m aOD. This deposit is located mainly over Lower Calcareous Grit and Hambleton Oolite and extends onto Black Hambleton. North of this some patches of upland peat also have also been mapped on the Cleveland Hills, but are not mapped as Winter Hill soils by the Soil Survey. The other main peat area mapped by BGS is at Egton High Moor on the central watershed of the Moors. Here there is one large area of 'BGS-peat' on the west and south-west sides of the Pike Hill, which includes Pike Hill Moss and Yarlsey Moss. The other is on the south-east side of the hill, around the head of Collier Gill. Mapped peat also extends to some small extent down the headwaters of other streams that drain this area, though it is not clear if all these deposits can be considered to be blanket bog peat. Peat is also mapped in three narrow bands on the north-east side of the hill, in the vicinity of Murk Mire Moor, but this thought to represent the infill of glacial channels. The main areas of BGS-mapped peat on Egton High Moor are situated on potentially permeable Moor Grit and Scarborough Formation rocks, not on the younger Long Nab member rocks, which were regarded (under the name of 'Upper Estuarine Beds') as being on the surface "the wettest of all the Oolitic strata" (Fox-Strangways, 1892) and which might be thought to be particularly conducive to paludification and blanket peat formation. However, thinner blanket peats (unmapped by BGS) do occur over Long Nab member and Cloughton Formation rocks and there are also some isolated pockets of deeper peat over depressions within these rocks.

The blanket peats of the Moors vary considerably both in depth and in character. In many instances the basal peats are rich in wood remains. Above this perhaps the most typical profile is one formed from a humified or strongly humified peat, dark and amorphous, or with remains of *Calluna vulgaris* and *Eriophorum vaginatum.* Overt remains of *Sphagnum* are generally sparse or absent. Exceptions to this generalisation occur in some depressions or near valleyheads draining the main watershed, but it is not clear that these are necessarily ombrotrophic.

Much of the blanket peat of the 'central watershed' of the Moors appears to have started to form after the Elm decline (Flandrian III), with pockets of earlier initiation, often associated with shallow depressions. These latter deposits may have been initiated in response to increase wetness at the Flandrian I/II boundary, the later ones possibly in response to forest clearance (Simmons, 1969; Simmons & Cundill, 1974).

Elgee (1912) identified two additional peatland sites embedded within moorland east of the Eller Beck–Newton Dale glacial channel. He regarded these as being different to those that formed much of the moorland further west. They were May Moss (extant) and Harwood Dale Moss (once turbary, now largely afforested). Both occupy shallow basins within moorland and seem to have (May Moss) or once to have had (Harwood Dale Moss) more affinities with raised bog than with blanket bog. Both have been mapped as peat by BGS and, in the case of May Moss, as Winter Hill soils by the Soil

Survey. At the edges of the main areas of moorland, small areas of mire may occupy the channels of small streams that drain the moors, often contacting rapidly downstream, especially where the slope is steep. Exceptions can be found to this generalisation and a particularly good example of a long, narrow valley, with much wetland interest and intimately embedded within moorland, occurs near the eastern side of Fylingdales Moor, where a long channel draining south-eastwards from Biller Howe Dale to the Jugger Howe Beck supports a series of mostly soligenous mires. West of Fylingdales, Fen Bogs forms an important wetland site which drains both north (into Eller Beck) and south (into Newton Dale) across a watershed within a glacial outflow channel. At least the watershed areas of this mire can be considered to be peripheral to the flanking moorland surfaces.

Some details of selected individual moorland sites, for which some information is available, are given below. They are arranged in west–east sequence across the North York Moors

3.3 Arden Great Moor

There is a quite extensive but isolated area of apparent blanket peat, up to about 2 m thick on flattish ground on Arden Great Moor (NGR: SE 500928), at about 360–370 m aOD, located partly over Corallian Oolites, partly upon Lower Calcareous Grit. When described by Elgee (1912) this was covered primarily by *Calluna vulgaris* and *Eriophorum vaginatum* and there was "an almost total absence of Sphagnum and other moorland plants", which was attributed to the dryness of the surface. On this account, Elgee also commented that "the moor is not strictly speaking a Moss, whatever it may have been when the name was applied". He also commented that "Arden Great Moor is perceptibly higher in the centre, due, I think, to the form of the rock floor…" (*i.e.* not to autogenic doming of the peat).

Elgee (1912) gave the following 'section' for the site:

Peat	2–6 feet, variable
White pebbles of Lower Calcareous Grit	
Band of thin pan	¼–½ inch thick
Clayey soil	

No recent information on vegetation and environment is currently available. The comments of Elgee suggest that the vegetation then was a form of M19 or M20.

The steep slopes below Arden Great Moor, particularly on the west and south sides, support a number of small calcareous, soligenous mires, typically with M10. These appear to be fed by groundwater outflow from the rocks below the blanket peat (Corallian Oolites and Lower Calcareous Grit) and this site provides a curious juxtaposition of calcareous minerotrophic and ombrotrophic habitats. It is possible that iron pans or other induration layers may have helped ombrotrophic conditions and peat surmount the relatively permeable, base-rich strata over which they have developed, though Elgee (1912) emphasised the thinness and irregularity of the pan at Arden Great Moor (and its apparent absence from other deep-peat sites elsewhere in the North York Moors). Frost (1988) has recognised the occurrence of peat over oolites on the Hambleton Hills, but provided no details or comment.

3.4 Egton High Moor

Egton High Moor forms part of the central watershed of the North York Moors, with a summit at 326 m aOD at Pike Hill. BGS-mapped peat is draped across the ridge west of the summit both to the north and south, but it mostly occupies a broad, very shallow depression which slopes very gently south-west to Yarlsey Moss and Bluewath Beck–Wheeldale Gill. South-east of the summit there is a smaller area of BGS-mapped peat around the head of Collier Hill.

The summit of the watershed at Egton High Moor is comprised of Scarborough Formation rock overlain, particularly on the higher part of the ridge by Moor Grit. These are underlain by older

Cloughton Formation rocks that are exposed on both the north and south slopes of the Moor, including much of the length of Wheeldale Gill. South of Wheeldale Gill, over much of Wheeldale Moor, the Scarborough rocks and Moor Grit are mostly covered by younger Long Nab deposits. These generally have a poorly-drained surface but do not appear to support blanket peat, possibly because of the lowering altitude and because the slope is too steep. The association of the BGS-mapped peat with areas of Moor Grit and Scarborough Formation on Egton High Moor may be because these occupy the highest ground and form a shallow slope, especially in the Pike Hill Moss–Yarlsey Moss trough. However, it is possible that the spreading of peat down some of the valleyheads that drain the watershed may partly reflect flows of minerotrophic water, either as surface run-off or perhaps some groundwater outflow.

3.4.1 Pike Hill Moss

The area of peat near and south-west of the summit of Pike Hill is known as Pike Hill Moss (NGR: NZ 758 013) and at the time of Elgee (1912) was extensively dug for peat ('Pike Hill Peat Holes'). He commented that "The Pike Hill Peat Holes are extensive, and the cutting which is in the form of a semicircle can be followed for half-a-mile or more". "The face of the peat cutting is from six to eight feet high, the hard white Moor Grit forming the surface rock" (Elgee, 1912). The exact location of the workings referred to is uncertain, but the 1st edition 6" County Series Ordnance Survey map of 1853 marks several likely spots connected to the Glaisdale–Rosedale road by rough tracks: High Birchwood Peat Bog (NGR: NZ 764 017), and Duck Ponds Peat Bog (NZ 769015), as well as a couple of 'Duck Ponds', which may perhaps represent the re-flooded remains of old turbary. [However, the 1st edition 1" OS map of 1861 labels these as 'Coal Pits'; BGS mapping shows an inferred coal seam within Cloughton Formation rocks a short distance west of the Glaisdale–Rosedale road.] No more recent vegetation of stratigraphical data have been found for Pike Hill Moss.

3.4.2 Yarlsey Moss

Yarlsey Moss (NGR: NZ 762005) is at about 310 m aOD, at the lower, south-western end of the Pike Hill Moss trough on part of the south-west side of Pike Hill. It is located around the headwaters of Wheeldale Gill, to which it drains southwards. Some of the area supports heather-dominated vegetation on partly-drained peat and Chiverrell stated that "The centre of Yarlsey Moss is ombrotrophic, which is largely the result of its location on the watershed between Wheeldale Gill and Winter Gill" (which is north-draining and west of the Wheeldale headwaters).

Elgee (1912) considered Yarlsey Moss to be different from other moorland mosses and noted that whereas Pike Hill Moss supported mainly cotton grass and heather, Yarlsey Moss was "clothed with tall Rushes, principally *Juncus communis* [=*effusus*] … Underneath and between the tall plants are extensive beds of Sphagnetum, very wet and dangerous to traverse. At intervals no rushes occur, and then the typical *Sphagnum* Bog – the Sphagnetum – displays its treacherous nature".

A stratigraphical core from Yarlsey Moss, made for pollen analysis and with sparse macrofossil details (Simmons & Cundill, 1974) consisted almost entirely of some 2 m depth of "mid brown monocot peat with occasional *Eriophorum* remains and bands of *Sphagnum* at 0.83–0.87 m and 0.94–0.97 m" over "impenetrable rock material". Simmons & Cundill regarded this deposit as blanket peat, but the possibility that it is weakly minerotrophic cannot be discounted. This core was made at NZ 762 005 on the western side of the moss

Chiverrell subsequently provided a more detailed 2.4 m depth core from part of Yarlsey Bog supporting heather-dominated vegetation. This was located on the east side of Wheeldale Gill (at NZ 760 005) and it is not clear what part of the mire it represented, topographically. Nor have data on the sub-surface topography of the site have been presented. The lower 90 cm of the core proved a well humified peat, mainly monocots and Ericaceae but with a layer of moderately humified

Sphagnum–monocot peat sandwiched between them at 152–185 cm bgl. Above 130 cm, to near the surface, the peat was a much fresher *Sphagnum*–monocot with thin layer of Ericaceae. This upper peat was composed mainly of *Sphagnum* sect. *Acutifolia*, though with small amounts of *S. magellanicum* and *S. papillosum, a*nd its inception was dated to around AD 400–600. Chiverrell considered that "Yarlsey Moss displays the classic characteristics of an ombrotrophic mire, with an ombrotrophic flora distributed over a mosaic of hummocks and hollows". This may be correct, but equally the peat composition of the peat above 130 cm depth (as shown by his macrofossil records) is also compatible with a weakly minerotrophic rheophilous system, with an M21-like vegetation. In the absence of further cores and details of the topography of the basin, no clear insights can be gained from these data.

A short distance south of Yarlsey Moss, close to Wheeldale Gill, Simmons & Cundill (1974) reported a 'Wheeldale Gill' core from NGR: NZ 760 997. This consisted of about 1 m depth of peat over sand and gravel. The basal peat, dated to 2640±80 BP, was wood peat, which comprised almost half of the deposit. Above this was essentially a *Calluna*–monocot peat, various described as 'dark brown', 'compact' and 'dry', and was perhaps a more characteristic thin blanket bog peat.

3.4.3 Collier Gill headwaters

The peat area around the head of Collier Gill appears once to have been a site of considerable turbary. The 1st edition 6" County Series Ordnance Survey map of 1853 mapped three areas as 'Peat Moss' and a larger area as 'Black Pits'; these were connected by rough trackways to the Egton Bridge–Cropton Road. At NGR: NZ 786009 Simmons (1969) reported some 2 m depth of peat, comprised of a surface 75 cm of *Calluna–Eriophorum* over almost 1 m thickness of a "dark brown to black largely amorphous peat, underlain by some 0.4 m of a basal wood peat". There were also two layers of wood sandwiched within *Eriophorum* peat higher in the profile. This may be regarded as a form of blanket peat, though it may also be noted that Elgee (1912) observed that "at Pike Hill Moss the hill peat passes into valley peat at the head of Collier Gill."

3.5 Fen Bogs

Fen Bogs is a large peatland site, about 1.5 km long and typically somewhat less than 0.2 km wide, which occupies the bottom of curving glacial channel. Topographically, it can be considered a 'Trough Wetland' (see Wheeler, Shaw & Tanner, 2009), which straddles a low watershed (at about NGR: SE 853 9783), draining to both north (to Eller Beck) and south (to Pickering Beck). The site has been examined in some detail by Atherden (1976) and Eades *et al.* (2017). The highest peat surface level (about 164 m aOD) was measured at the eastern edge of the watershed, which falls by 4 m to the southern end of the SAC, over a distance of about 1.12 km. North of the watershed, the contours of Atherden (1972) indicate a drop of about 3 m to the northern end of the mire, over a distance of about 0.33 km. The mire is thus largely unconfined longitudinally but strongly confined laterally by the slopes of the trough.

The rather narrow, trough-like character of the site, with steep flanking slopes has resulted in minerotrophic conditions over much of the surface, derived from groundwater outflows and surface run-off from the slopes and margins. Minerotrophic surfaces support a range of vegetation types, including M10, M14 and S27 in the more base-rich locations and M21 and M4 in more base-poor conditions. Patches of M18 vegetation also occur associated with the highest part of the mire, *i.e.* straddling the watershed north–south, and this appears to be ombrotrophic in character. Along the eastern side this is separated from the rising upland slopes by a band, mostly a soakway, of minerotrophic conditions, which flanks the ombrotrophic area and which appears to represent some form of spring-fed lagg. There is less clear evidence for a natural lagg-like feature along the western margin where the edge of the mire has been much modified by the construction of a railway line in 1837. Whereas the putative ombrotrophic area follows a dome north–south, it is tilted east–west, probably on account of drainage and peat shrinkage associated with the railway (Atherden, 1972). This may also have facilitated the east–west spread of some base-rich water across parts of the M18 area, either through ditches or soakways. However, most soakways and drainage of minerotrophic water occurs longitudinally south and, especially obviously, north of the M18 area and, because of its unconfined character, is manifest as a transition into a broad area of fen rather than a lagg.

Away from the margins, the peat at Fen Bogs is rather deep, typically between about 5 and 9 m depth, but more than 11 m in some places. Both Atherden (1976) and Eades *et al* (2017) provide sections for the site, and it is clear that the peat surface is partly domed along the length of the mire, broadly reflecting the underlying mineral surface of the somewhat humped outflow channel. The slightly domed surface configuration of the ombrotrophic area thus reflects the topography of the channel, deep below the surface, at least longitudinally.

Atherden (1972, 1976) demonstrated that the channel was lined by a blue-grey solifluction clay believed to date from the late-Devensian period, over which there was a basal peat rich in wood remains. There was no stratigraphical evidence for a protracted early phase of lacustrine conditions. Monocot peat formed the bulk of the peat over the wood-rich layer, and appears to represent a rather swampy deposit, rich in *Cyperaceae* and often with much *Phragmites*, and with occasional seeds of *Menyanthes* and *Potamogeton*, though in places it contains some wood remains. Peat rich in *Sphagnum* is widespread, mainly in the top layer of the deposit, and can be more than 1 m deep, but thinner, deeper layers also occur within the reed–monocot peat, and in a few instances a band of *Sphagnum*-rich peat has been replaced by monocot peat at the surface.

Atherden (1972) considered that "Within the last 150 years drainage schemes have lowered the water table and changed the mire from a topogenous to an ombrogenous one. This change has resulted in the extension of Sphagnum spp and the establishment of a more acid-tolerant flora on the main part of the mire, while the reedswamp community has become confined to the wetter and more base-rich environment of the drainage channels at the southern end of the mire." However, Chiverrell (1998) subsequently considered that "the mire was colonized by an ombrogenous mire flora *circa* cal. AD 1100". He documented subsequent changes in both the abundance of *Sphagnum* species and their identity, and related these to possible changes in wetness of the mire surface subsequent to 1100 AD. However, because these data were based on a single core, it is not possible to determine whether they represent just local changes, perhaps related to a local peat building cycle, or reflect wider changes across the mire surface. It should also be noted that he thought "it is possible that the presence of *Sphagnum papillosum* in the fossil record signifies the occurrence of a locally ombrogenous flora and ombrogenous facies on the mire surface". However, *S. papillosum* is also a characteristic component of weakly minerotrophic surfaces, such as support M21 vegetation (for which it is a naming species).

Of particular interest, Chiverrell (1998) noted that "in the surface layers of peat (5–30 cm), *Sphagnum* remains become virtually absent, before reappearing on the mire surface. This decline of *Sphagnum* is not dated: however, the chronology developed for the peat sequence indicates that the changes probably occurred during the nineteenth century and may be broadly synchronous with the construction of the Whitby to Pickering railway across the western edge of the mire in AD 1836. Drainage schemes associated with railway construction, and perhaps physical damage of the mire surface, may be responsible for the decline in *Sphagnum.* However, *Eriophorum vaginatum,* Ericaceae and *Sphagnum papillosum* become more abundant in the top 10–15 cm of peat, reflecting the recovery of a typical mire flora." This seems to be a reasonable interpretation of the observed sequence, though it would be of much interest to know how widespread the '*Sphagnum* decline' was across the mire.

With present information, it is not possible to be *certain* that any of the peat at Fen Bogs is truly ombrotrophic, but this seems likely to be the case. However, any ombrotrophic peat at the surface is generally thin, less than 1 m depth. It seems likely that drainage associated with the construction of the railway either induced or accentuated the ombrotrophication process, and much of the conservation and telmatological interest of Fen Bogs resides in the juxtaposition of minerotrophic surfaces with this.

3.6 Harwood Dale Moss

Elgee (1912) identified the location of Harwood Dale Moss as being close to the Falcon Inn (NGR: SE 972982), in a slight depression south of the watershed, more usually termed 'Harwood Dale Peat Holes' and about one third of a mile across both north–south and east–west. In fact, there are three areas near to the Falcon Inn that are labelled 'Peat Moss' on the 1st edition 6" Ordnance Survey map, one of which is not in Harwood Dale parish. Of the two, the largest area mapped as 'Peat Moss', at about SE 969985, corresponds best with the dimensions cited by Elgee and also to an area mapped as peat by BGS. It is at about 200 m aOD and is now largely forestry plantation. This has also been recognised as Harwood Dale Moss by Atherden (1989) and Chiverrell (1998) (though both specified NGR: NZ 967988). Fox-Strangways & Barrow (1915) reported that peat was dug there at the time of their survey (1882). Elgee likewise recognised it as a turbary, but stated that it was still about 30 ft (9 m) deep in the middle and was apparently higher in the centre than around the periphery. This raises the possibility that it may have been a small raised bog-like structure, as is the case for May Moss (see Section 3.8).

The considerable depth of peat reported by Elgee may be because, like May Moss, this mire has developed in a shallow depression, or could be an error. Few data on sub-surface topography are available. Erdtman (1928) provided a "very schematic section" which showed the peat deposit in a basin or a trough with a very slight elevation of the surface away from one margin (the other margin had been dug for peat, with a cutting face of some 3 m depth). Overall, the stratigraphy indicated a quite thick accumulation (> 3 m in the deepest part) of "Vaginatum-peat" upon about 1–2 m of "Forest peat". He provided some further details of the peat, based on observations by Whitaker (1921)[1] (Erdtman, 1927):

A — A top layer, about I0 feet with *Sphagnum*, *Eriophorum vaginatum*, ericaceous plants etc.

B — A forest layer, about 4 feet, with twigs, stools and roots of trees (over hundred annual rings were counted from some of the pine stumps); also pine cones and hazel nuts.

C — A fen layer, from a few inches to 2 feet, with *Scirpus, Juncus, Phragmites etc.*

This profile corresponds fairly well with a more recent record of the stratigraphy (Atherden, 1989) "at the edge of the cut area" where the top 2.35 m could be "sampled directly from the exposed peat face". Here the peat was about 3.75 m deep, over mineral ground. The basal peat was rich in wood remains, layered with, and giving way upwards into, a monocot peat. Above about 2.5 m bgl this was replaced by *Eriophorum* peat, which contained some woody fragments. No *Sphagnum* peat was shown in the profile, but strongly fluctuating counts of *Sphagnum* spores were evident in the pollen diagram. Pollen analysis suggests that the basal peat started to form in early Flandrian times, whilst radiocarbon dating put the transition to the base of the *Eriophorum* peat at about 3360 BC and may correspond broadly with Neolithic activity in the area.

3.7 Kildale Peat Moss (West House Moss)

This site is located on a watershed within a valley trough, at about 175 m aOD at NGR: NZ 633095 and is marked by a significant accumulation of valley-bottom peat (about 94 ha area). It is included here for comparative purposes and because of its close proximity to moorland on the flanking valleyside slopes.

[1] Not seen by us.

The watershed is marked more-or-less by a minor road which crosses the peatland north–south. West of the road, drainage is westwards through a long strip of peat where the valley-bottom narrows beneath Crag Bank Wood, into the River Leven (which originates from springs up to about 2 km away, on the moors south of the mire (Warren Moor (335 m aOD) and Kildale Moor (279 m aOD)). It is thought likely that the part of the mire drained by the Leven was minerotrophic and the strip between the river and Crag Bank Wood has been mapped as 'Old Fish Pond' on historic County Series 1:10560 Ordnance Survey maps since the 1st edition survey of 1856.

East of the road, the peatland occupies a somewhat wider, flatter valley bottom and forms the headwaters of the eastward-draining River Esk. Some small springs occur around the flanks of the mire and may influence its margins. This area is labelled as 'Peat Carr' on County Series 1:10560 maps from 1856 onwards, but is marked as rough pasture, not as woodland.

The mire is crossed by the North Yorkshire and Cleveland Railway, which was built eastwards between Picton and Grosmont, with construction reaching Kildale in 1858 and Grosmont in 1865, with a summit at Kildale Peat Moss (Benham, 2008). Part of this branch remains extant (as the 'Esk Valley Line'). The 1st revision 1:10560 OS map of 1895 shows a junction immediately west of the road with a short tramway that ran up the Leven valley, alongside the river, to some old ironstone workings. West of the minor road, the railway flanks the northern side of the peat deposit, as mapped by BGS, but on the eastern side it runs across it.

The site was described (as "Kildale Carrs" and "the great peat carr") by Elgee (1912) and more succinctly by Erdtman (1927), both apparently referring to the 'Peat Carrs' east of the minor road:

> "This is a typical moss with the centre slightly higher than the margins. The surface vegetation consists of *Scirpus cespitosus* and *Calluna vulgaris* as dominants, with a sporadic diffusion of *Eriophorum vaginatum.* Intermingled with these are *Drosera rotundifolia*, *Erica tetralix, Nardus stricta, Narthecium ossifragum, Potentilla tormentilla* [*erecta*], and scanty patches of ill-grown *Vaccinium myrtillus.* Towards the margins of the moss, the ground is drier and grasses come in, such as *Deschampsia flexuosa, Molinia caerulea, etc."* (Erdtman, 1927).

Elgee (1912) puzzled over the relative dryness of this site and seems to have ascribed it to a balance between meteoric exchanges, rather curiously because "there does not appear to be any escape for their water". However, it is almost certain that there was significant drainage associated with the railway line, and possibly also with peat digging at the eastern end where "in some old peat cuttings there is a rich growth of *Eriophorum angustifolium* and the Pink Bell Heath with the Common Tormentil in the wettest places. This typical bog vegetation is in marked contrast to the drier grass land on the summit of the cuttings! Here and there gorse bushes occur, even towards the highest part of the peat carr …"

In 1925 G. Erdtman visited the site with Elgee and "made a boring at a central point south of the Commondale–Kildale railway" (Erdtman, 1927). This was apparently at the highest point of the moss:

A: 425 cm **cotton-grass-peat,** especially in the lower part parts not quite typical; remains of pine at the base.

B: 85 cm **birch forest peat,** with seeds of *Menyanthes* and radicells of *Equisetum*

C: 45 cm **muddy detritus,** with seeds of *Menyanthes*.

D: 35 cm **clay**, grey, sandy

These details were essentially replicated by Erdtman (1928), with the difference that he described the top peat layer as "moss-peat with wood at the base". Erdtman (1928) also provided a west–east section based on five cores which indicates a strongly lenticular deposit in which the dome is somewhat offset to the west of the bottom of a shallow basin, which contained "muddy detritus" in its lowest parts. As shown in his diagram the dome of the deposit was some 2–3 m above the level of the western margin, some 200 m away and some 4 m above that of the eastern margin, a similar distance, but in both cases the margins were on fen (“birch forest”) peat.[1]

More recently, the site was re-examined by Jones (1977) who considered it a raised bog. He apparently bored two sections across the Moss. The location of neither is shown, and the stratigraphy of only one (west–east) is indicated. Jones’ overall stratigraphy shows some considerable differences from that of the west–east section of Erdtman (1928). One difference is that whereas Erdtman found the bottom of the basin with its ‘muddy detritus’ to be skewed to the east of the peak of the dome, Jones found it to be to the west of this. A more consequential difference is that Jones reported peat above the thin layer of ‘clay mud’ in the bottom of the basin or, where this was absent, above the tenacious basal clay was “a *Phragmites* peat which is covered by a wood peat and a *Carex*-dominated peat…Within the *Carex* peat are three main layers [each actually fairly thin] of *Sphagnum* peat, the intermediate attaining the maximum extent and thickness”. Some of these differences (such as the failure of Erdtman to report a significant basal layer of *Phragmites* peat) could conceivably reflect differences in the locations of the sections. However, Jones’ designation of the main dome of peat as *Carex* peat with layers of *Sphagnum* would seem to make little sense if the site was a small raised bog. It is possible that this may be an error for ‘*Eriophorum* peat with layers of *Sphagnum*’, which would be compatible with Erdtman’s observation. The maximum thickness of this peat (above the wood peat) according to Jones was about 4 m, which matches the thickness reported by Erdtman.

Overall, it seems most likely that the ‘Peat Carrs’ area east of the minor road consisted of an ombrogenous dome of peat, developed from fen and, locally, shallow open water within a shallow Devensian basin in a watershed location. Its margins appear to have been fed by telluric water, originating from run-off and springs on the nearby valleyside slopes. This part of the site may have been drained in association with the construction of the railway across it, or drainage could pre-date this.

3.8 May Moss

May Moss occupies a shallow depression on Allerston High Moor at NGR: SE 875960 and straddles the main watershed of this part the North York Moors, at about 244 m aOD. It is flanked, except along the northern side, by Forestry Commission plantation, which has probably partly drained the site. The surface and sub-surface topography of the site were reported by Atherden (1972), though the two are not easily related together (the topographical sections show surface elevation but not the configuration of the basins). The mire occupies two basins, both with more than 5 m depth of peat infill, though the western basin is the deeper of the two. They are mostly separated by a shallow, partly peat-covered, ridge, but connected by a narrow, peat-filled channel at the northern edge. The larger, western, basin drains from the north-west side of the Moss northwards into the Eller Beck, whilst its southern margin and the eastern basin drain southwards into the Long Grain. However, the surface of the eastern basin is apparently higher than that of the western, creating the possibility of some drainage westwards into the northern end of this through the connecting peat-filled channel.

Elgee (1912) noted that “The centre of the moss is considerably higher than the edges, perhaps ten feet, if not more” and he attributed this as “not due to the form of the rock floor upon which the peat has accumulated; on the contrary it is entirely due to the manner of growth of the peat itself”. And although it is not clear how much information Elgee had about the sub-surface topography of the site, his assessment is essentially supported by the work of Atherden and some informal probings (B.D. Wheeler, *pers. obs.*). The dome of peat is nowadays not as prominent as it was when

[1] Erdtman (1927) also stated that “A record of nine borings in the Kildale Moss has been published in *Proc. Cleveland Naturalists’ Field Club* (Hawell, Fowler, and Huntingdon, 1913)”. This has not been seen by us.

noted by Elgee, probably because of peripheral drainage associated with afforestation. [Elgee held the view that *natural* outflows either did not exist or would have been sporadic. He also observed that "Where Eller Beck issues out of May Moss, it forms a waterfall four or five feet high over a ledge of peat which is slowly being eroded back"; the reason for this is not clear.]

Fox-Strangways & Barrow (1915) reported that peat was dug at 'Allerston High Moor' at the time of their survey (1882), which may well refer to part of May Moss. Elgee (1912) considered it likely that May Moss was the 'Moss' referred to in a charter granting a large tract of land to Whitby Abbey at the time of Henry I (early 12th century) which, if correct, raises the possibility that any turbary there may be of some antiquity. However, Atherden (1979) did not report a hiatus or other disturbance in her peat core from the site.

Atherden (1979) reported a maximum peat depth of 6.4 m at May Moss. Peat was developed upon weathered sandstone (Kellaways Rock, now Osgodby Formation). She observed that "Thirty borings revealed that the stratigraphy was fairly homogeneous, consisting of alternating layers of *Sphagnum* peat and monocot. peat with abundant *Eriophorum* fibres. At the base of the peat in some places a detrital deposit with wood and charcoal fragments was found, but no other wood remains were encountered. The top few centimetres of peat were drier and contained remains of Ericaceae and monocots." There was no evidence for basal aquatic plants or sediments other than the detrital wood, though the lower peat layers appear to be dominated by monocots. She considered (using pollen evidence) that peat started to form in early Flandrian times (Flandrian 1b, West 1970), when the site appears to have been surrounded by woodland.

It may however be noted that the stratigraphical data of Atherden's core from May Moss suggest that *Sphagnum* remains became more prominent in the upper part of the profile, above about 2 m bgl. This was recognised subsequently by Chiverrell (2001), who considered that the rise of a "*Sphagnum*-dominated stratigraphy", was "the most significant change at May Moss", though it was not synchronous across the basin. He considered that it occurred first over the deepest peats and spread thence towards the shallower margins, which he attributed to "the control topography exerts over bog development", though with only four of his own cores, all of them quite close to the southern margin of the western basin, the overall pattern of spread of *Sphagnum* dominance in the basin remains uncertain, or how it relates to his palaeoecological evidence for increased wetness within the basin.

The Soil Survey has mapped the area of May Moss as Winter Hill Association soils, a category used by them for blanket peat elsewhere in the North York Moors. Chiverrell (2001) also described the site as 'blanket bog' ("May Moss is the only extensive tract of unmodified actively accumulating deep blanket peat on the North York Moors"), but it is not clear why. The deep peat at much of May Moss, quite fresh and loose in some of the upper layers, is quite different from blanket peats elsewhere on the Moors, and with its (former) shallow dome and its M18 vegetation is more suggestive of a small raised bog, though one which has apparently developed by paludification. Chiverrell has also pointed out that peat has spread partly across the ridge that helps to separate the two basins, by a process he refers to as "lateral paludification", but in the absence of appropriate topographical and stratigraphical data, it is not possible to assess whether this was just a reflection of the overall rise in the level of the surface of peat accumulating within the basins, or if at some stage the surface of the peat spreading across the ridge was significantly higher than that in either of the basins.

Mean annual rainfall reported for 1981–2010 from nearby Fylingdales is 978.9 mm, with the lowest monthly rainfall average in May (57.4 mm). Mean annual temperature maximum is 11°C, with highest monthly maximum averages in July (18.3°C) and August (17.9°C). Actual and Potential annual evaporation totals for this part of the North York Moors may be in the region of 550 –600 mm, indicating a significant precipitation excess.

The vegetation of the main area of the moss is largely referable to M18, and it supports *Andromeda polifolia, Sphagnum papillosum, S. magellanicum etc.* It is adjoined on the north side by heather moor on shallower peat, and elsewhere by plantation woodland.

3.9 Simon Howe Moss

Simon Howe Moss is a rather nebulous deposit of peat located at NGR: SE 828981 about 1.5 km south-east of Fen Bogs. It lies at about 250 m aOD in a narrow, shallow wet depression that forms the headwaters of a small stream, which flows south-westwards to join the Blawith Beck. The eroding peat surface supports an impoverished mix of *Eriophorum vaginatum* and *Sphagnum* spp., with drier areas dominated by heather and with *Juncus* in and alongside the stream channels.

The peat forms a valleyhead infill that slopes gently southwards and is deepest along the axis of the trough (Atherden, 1972). Atherden (1972, 1979) has reported a maximum peat depth of 3.75 m, consisting "of alternating layers of *Sphagnum* and *Eriophorum* peat, and only two fragments of wood were encountered in the stratigraphical borings", and with similarities to that recovered from May Moss (see Section 3.8). Remains of *Phragmites* were recorded below about 1.6 m bgl. The basal peat was humified and compacted, and apparently without much woody material. Below this was some 20 cm of a stiff blue-clay located upon bedrock. This is referable to the Long Nab member of the Scalby Formation, but the eastern side of the mire flanks a small outlier Osgodby Formation sandstone over a thin layer of Cornbrash. It is possible that this may supply (or once have supplied) groundwater to the mire which, along with run-off from Long Nab rocks may have created weakly minerotrophic conditions in the Moss. Despite its depth, this peat deposit was not mapped by BGS, nor is it shown as Winter Hill soil.

Pollen analysis of a core from Simon Howe Moss suggests that peat started to form in the Bronze Age.

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4 The Border Mires of Cumbria & Northumberland

4.1 Background

The Border Mires are a series of more than 60 mires spanning the border between Cumbria and Northumberland, just to the south of the Scottish–English border. This is an area of irregular terrain consisting of a series of hills, ridges, basins, troughs and small valleys, most of which drain to the River Irthing or the River North Tyne. The area has an altitude ranging from about 200 m aOD in the south and east, to about 400 m aOD in the far north-west, and receives an average of 1252.8 mm of rainfall per annum (Spadeadam Station – Met Office, 1981–2010). Chapman (1964b) estimated annual evaporation at Coom Rigg Moss to be 532 mm in 1958–9, and 424 mm in 1959–60, indicating a substantial precipitation excess. This region includes the area of Spadeadam Waste (now called Spadeadam Forest) and the nearby Wark Forest.

Many of the Border Mires are formally protected as SSSIs and components of SACs, and Coom Rigg Moss was designated as a National Nature Reserve as early as 1960. There are also several non-statutory sites for which there is a long-term aim of clearance of conifer plantations as they reach maturity (Dearnley, 2010).

4.1.1 Geology and soils

The geological characteristics of the area have been mapped by BGS on England & Wales sheet 12 (‘Bewcastle’), which is supported by a fairly modern *Memoir* (Day, 1970). The area is towards the eastern side of sheet 12 and continues into sheet 13 (‘Bellingham’), which has a slightly more recent *Memoir* (Frost & Holliday, 1980).

The area is located within the ‘Northumberland Trough’; the bedrock is formed from a thick accumulation of the Dinantian Tyne Limestone Formation (formerly the ‘Upper Border Group’), which consists of inter-layered sandstone, mudstone and thin limestone, locally with thin coals, dipping gently towards the south-east. Many of these units are laterally impersistent, but some more prominent sandstone and limestone bands are sufficiently distinct to be mapped separately. The rocks have been subject to quite complex folding and faulting, but in the Border Mires area the details of this are considerably obscured by a thick mantle of Drift (Day, 1970). Till is extensive, with prominent drumlins in places, mostly aligned north-east–south-west, and depths of up to about 30 m have been reported. Peat is also widespread, mostly in and around hollows, where it is probably mostly underlain by Till. It becomes most extensive on the higher ground to the north and west.

In the area of Spadeadam Forest, the Soil Survey mapped extensive patches of peat soils as part of the Longmoss Association. On the higher ground to the north and west this is replaced by peat soils of the Winter Hill Association. This difference may coincide broadly with a distinction made, but not mapped, by the BGS into ‘basin peat’ and ‘hill peat’ (Day, 1970). In this regard Day’s comments are apposite: “Two main types are recognised [by BGS], namely hill peat and basin peat, though they are not distinguished on the one-inch [geology] map. Their separation depends not so much on difference of growth, composition and appearance but rather on their geographical setting; both types fall within the definition of bog peat as defined by Pearsall (1950, p. 65)”.

4.1.2 Afforestation

Prior to 1926 most of the uplands of northern England are likely to have supported a range of acidic grassland, heathland and mire vegetation (Smith *et al.*, 1995). Timber shortages during the First World War resulted in the creation of the Forestry Commission (in 1919), in order to establish a strategic timber resource. This involved the gradual afforestation of large parts of the northern uplands, with most of the planting taking place in the period 1945–1960 (Dearnley, 2010). Afforestation encompassed many mire sites, which would have been drained then planted, or drained and left for later planting, often leaving only the central wettest parts of the mires open. Adjacent slopes were also drained and planted, and drainage ditches often ran across mires or around their margins (Lunn & Burlton, 2010).

During the early decades of afforestation, no assessment of the scientific or conservation importance of these mires was made, and huge areas of relatively intact mires on often very deep peat deposits were rapidly incorporated into the forest estate. Most of the Border Mires are now within Kielder Forest Park, which comprises Kielder Forest, Wark Forest, and Spadeadam Forest. Local naturalists and ecologists from academic institutions such as the University of Newcastle-upon-Tyne were aware of the presence of some of these sites from at least the 1950s. Northumberland & Durham Naturalists' Trust (now Northumberland Wildlife Trust) leased eight mires from the Forestry Commission in the 1960s, and at this time the collective name 'Border Mires' became used to refer to all the mires in the area (Lunn & Burlton, 2010).

4.1.3 Site accounts

The following sites have various combinations of relevant available data: vegetation types, peat depths, peat stratigraphy, and hydrological data:

- Butterburn Flow – vegetation, limited peat depth profile.
- Coom Rigg Moss – vegetation, peat depths, peat stratigraphy, hydrology, radiocarbon dating.
- Foalstand Rigg Mire – vegetation, peat depths.
- Hummell Knowe Moss – vegetation, peat stratigraphy.
- Long Moss – vegetation, peat depths.
- Prior Lancy Mire – vegetation, peat depths, peat stratigraphy.
- Sheep Rigg Moss – vegetation, peat depth, peat stratigraphy, radiocarbon dating
- Standing Stone Moss – vegetation, peat depth, peat stratigraphy, radiocarbon dating
- The Wou – vegetation, mire 'type'.

4.2 Butterburn Flow

Butterburn Flow SSSI is situated about 6 km north-east of the Spadeadam MoD base, at approximately NGR: NY 6744 7630. Covering about 409 ha, it is the largest of the Border Mires sites, and forms an important component of the Border Mires, Kielder–Butterburn SAC. Though it is surrounded by dense conifer plantations, most of the mire has remained unplanted with conifers, although substantial marginal parts have been affected by drainage ditches. The southern end of the mire, outwith the SSSI boundary, previously supported a forestry crop, but this was substantially removed as part of a European Union LIFE-funded rehabilitation project with ran from 1998 to 2003 (Northumberland Wildlife Trust, 2003).

4.2.1 Topographical context

Broadly speaking Butterburn Flow occupies an interfluve between the River Irthing and the Butter Burn. It is bounded to the north and east by the River Irthing, while its western edge is marked by the rising mineral ground of Gringarry Hill and Birky Shank (301 m aOD), Calf Hill to the north-west (about 282 m aOD), and Gowany Knowe (292 m aOD) to the south-west. A small stream, the Lawrence Burn, roughly bisects the site, flowing from near Birky Shank north-eastwards to join the River Irthing. The northern lobe of Butterburn Flow slopes down to the north-east from about 280 m aOD to 270 m aOD, where mineral ground (as mapped by the BGS) drops down to the river. The larger southern lobe of the Flow has a maximum elevation towards its western edge of almost 290 m aOD, and slopes steadily down to the south-east to an altitude of about 250 m aOD just above the confluence of the Butter Burn and the River Irthing. A smaller lobe slopes down to the north-east toward the ruins of Shank End, on the bank of the Irthing.

4.2.2 Geological context

BGS mapping shows that most of Butterburn Flow is underlain by mudstones, siltstones, sandstones and limestones of the Tyne Limestone Formation, with some smaller interleaved bands of Lower Millerhill Limestone in the south-eastern corner. Overlying the bedrock the BGS mapped a single body of Peat, broken only by the Lawrence Burn and the western prominences of Gringarry Hill, Birky Shank, Calf Hill, and Gowany Knowe, which are mapped as Till; Till is likely to underly the peat deposit itself. A narrow band of Alluvium is mapped along the valley of the River Irthing.

4.2.3 Vegetation

Barber (1981) described the northern and southern parts of Butterburn Flow separately. South of the Lawrence Burn the bog surface supports closely-spaced circular hummocks about 40 cm tall and 30 cm in diameter, separated by 20 cm wide channels. The vegetation was dominated by *Eriophorum angustifolium* and *Sphagnum magellanicum*, with *Erica tetralix* and *Calluna vulgaris* on the hummocks and *Sphagnum tenellum* and *Sphagnum cuspidatum* in the channels. Barber found the northern part of the Flow to be a slightly undulating lawn of *Sphagnum magellanicum* and *Sphagnum papillosum* beneath *Eriophorum angustifolium*, with low mounds of *Sphagnum imbricatum* and occasional hummocks of *Sphagnum fuscum*. Barber also noted a central region with several large circular pools fringed with *Carex limosa.*

A brief assessment of the vegetation of Butterburn Flow was made during a plant species survey carried out by Simpson (1997). He recorded three main vegetation types: "Deer-grass *Trichophorum cespitosum*-dominated bog; Purple moor-grass *Molinia caerulea* hummock grassland; and hill meadow grassland". Interestingly Simpson considered *Trichophorum cespitosum* to be dominant overall, in contrast to Barber's description from 1981, with *Erica tetralix* and *Eriophorum angustifolium* abundant on the "Deer-grass bog", and *Molinia* abundant throughout, but dominant around the edges of the bog plateau and in the Lawrence Burn valley. *Drosera rotundifolia* and *Narthecium ossifragum* were frequent, whilst *Drosera anglica* and *Rhynchospora alba* were locally frequent. He also noted *Carex magellanica* in a bog pool at NY 677 757, and *Carex pauciflora* at NY 662 761. However, he did not record bryophytes.

Jerram (2000) carried out an *NVC* vegetation survey at Butterburn Flow. He described the site as an "extensive blanket mire… bisected by the shallow valley of Lawrence Burn. The majority of the site lies on deep peat (>1 m depth)… covered by M18a *Erica tetralix–Sphagnum papillosum* mire… Of note is the constancy of *Andromeda polifolia*." Jerram also described large areas of bare peat and *Sphagnum cuspidatum* that he assigned to M2 bog pool vegetation, mingled with the M18. Towards the margins of the bog was a belt of "grassy blanket mire vegetation" that was assigned to M17 *Trichophorum–Eriophorum* mire, with locally much *Molinia caerulea*. Flushed areas within and around the margins of the mire supported acidic M6a, M6c and M6d *Carex–Sphagnum* mire, M23a *Juncus–Galium* rush pasture, and locally some patches of base-rich vegetation with affinity to M10a *Carex–Pinguicula* mire.

Smith *et al.* (2003) describe in passing the microtopographic variation typical across the site: "A hummock to hollow pattern with extensive lawns of *Sphagnum papillosum* and *S. magellanicum* and lower pools of open water with *S. cuspidatum, Drosera anglica* and *Eriophorum angustifolium*. Plus hummocks of *S. capillifolium* and *E. vaginatum* with moorland species such as *Pleurozium schreberi* and *Deschampsia flexuosa* on the hummock tops."

Yeloff *et al.* (2007) described Butterburn Flow as "one of four peat bogs in the UK that is transitional between an ombrotrophic raised peat bog and a patterned mire (narrow ridges divided by open water pools)". They considered that the mire vegetation was dominated by *Sphagnum magellanicum* and *Sphagnum papillosum*, with constant *Erica tetralix, Narthecium ossifragum* and *Vaccinium oxycoccos*, and abundant *Andromeda polifolia*. Hummock microforms supported *Calluna vulgaris,* whilst hollow microforms possessed *Rhynchospora alba.*

A 'broad-brush' *NVC* map provided by Natural England is provided below (Figure 2), showing most of the site to consist of M18 vegetation, with smaller fringing areas of M17 vegetation, and a little rush or purple moor-grass vegetation.

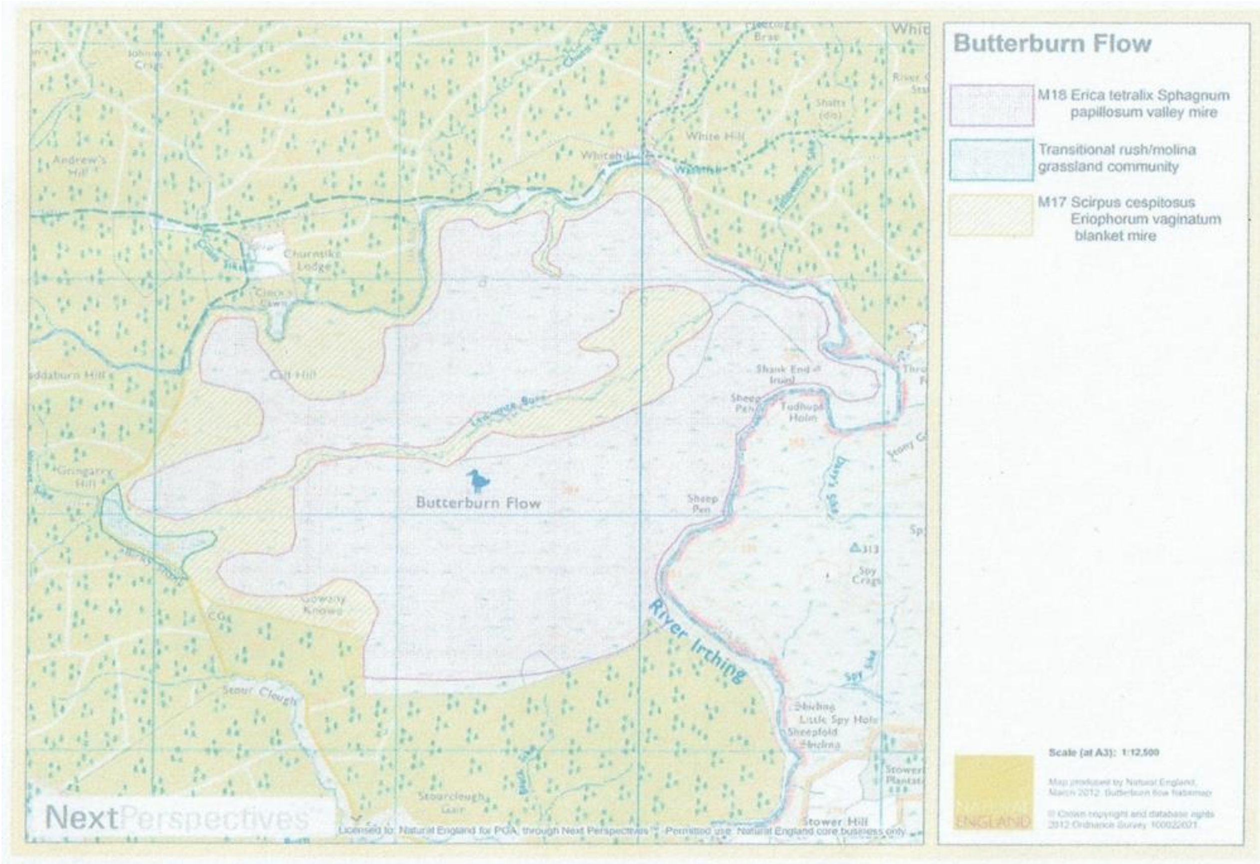


Figure 2. Butterburn Flow *NVC* map (Natural England *in litt.*, 2020).

4.2.4 Peat infill and characteristics

Barber (1981) described peat depth across the site as averaging 4–5 m, ascertained by several boreholes. Attempts to examine the uppermost stratigraphy of the site found the upper 20 cm to comprise very poorly humified *Sphagnum–Eriophorum* peat (H3 on the von Post scale), overlying a much more humified peat (H7–8) with *Calluna* remains down to at least 100 cm depth.

As part of a study aimed at determining the cause of vegetation changes across many of the Border Mires sites since widescale afforestation of the region, Hendon & Charman (2004) took 2 peat cores from the northern-most lobe of Butterburn Flow, and also provided a peat depth profile along two orthogonal transects from the same part of the mire, though they did not provide the raw data for this. They described Butterburn Flow as an "intermediate blanket-raised ombrotrophic mire" and referred to the northern part of the site as the "northern dome". Although the peat cores that were described by this study only sampled the uppermost 1 m of peat, the profiles provided in their Figure 1 showed peat depths of at least 8 m. The topography of the underlying mineral ground is suggestive of a shallow trough or basin constrained by a ridge of submerged mineral ground to the south. Rather than a domed surface the peat profile shows surface contours that undulate gently from east to west (about 1 m amplitude), and slope gently down to the river to the north, steepening rapidly at the margin of the River Irthing.

Later work by Yeloff *et al.* (2007) investigated peat cores from a similar position on Butterburn Flow. They recorded the maximum peat depth at that location to be 7.97 m and established the peat depth and stratigraphy by a series of six test boreholes on two intersecting transects, but they did not report the peat stratigraphy. They then recovered a 4 m peat sequence for pollen analysis and radiocarbon dating. The sample composition comprised mainly *Sphagnum magellanicum* remains to a depth of about 70 cm, replaced below this by *Sphagnum imbricatum*, with frequent charred *Calluna* remains, and occasional *Sphagnum* section Acutifolia leaves, to a depth of 400 cm. The base of the sample (i.e. halfway down the full peat profile) was dated to 4495 ± 45 years BP.

Hendon & Charman (2004) examined the assemblages of testate amoebae in the top 50 cm of two peat cores from Butterburn Flow, taken from lawns of *Sphagnum papillosum* some 10 m apart, which appeared to represent some 200 years of net peat accumulation. They considered that "Both profiles show a rise in water table from AD 1800 peaking around AD 1920–30 and then falling to lower values after 1950". There was some variation between the two cores, particularly regarding the magnitude of assessed change, with the inferred water table in one core being more stable than in the other. Overall, they considered that decadal averages in reconstructed water tables indicate an increase by about 3 cm between 1800 and 1920–30, followed by lowering to about 1990 and then a sharp increase by about 1 cm. The reconstructed decadal average at 2000 was some 1.5 cm higher than in 1800.

Hendon & Charman also examined the changing patterns of macrofossil composition over the same period but presented data for only one of the cores. In this, they found that near the bottom of the 50 cm core *S. imbricatum* was replaced by *S. magellanicum*, which itself then declined in favour of *S.* sect Acutifolia and *S.* sect Cuspidata (including *S. cuspidatum*). From about 30 cm below ground level there was a resurgence of *S. magellanicum* and then, above about 20 cm bgl *S. papillosum* became prominent. They considered that "The changes in plant macrofossil content are approximately coincident with changes in the testate amoebae assemblages and inferred water-table changes." They examined various possible explanations for this inferred change and concluded, partly because of the distance of their sampling site from pre-war forestry, that afforestation was unlikely to have had much of an influence on surface wetness and they suspected climate change to have been of greater importance. They do not appear explicitly to have considered the possibility (but see Hendon *et al.*, 2001) that autogenic growth dynamics of the mire surface, either generally or differentially, may have contributed to the changing observed patterns of macrofossil abundance and to the inferred changes in water table relative to the surface – a possibility that might help explain the disparity in the inferred magnitude of fluctuations within their two cores. Their chronologies indicate that some 20 cm depth of deposit has accumulated in one core since the 1950s, some 15 cm in the other, and this needs to be considered when assessing any likely impact of the inferred water level changes.

These comments are not intended to suggest that climate change since 1800 has not been influential upon surface water conditions at Butterburn Flow – it would be surprising if climatic variation did not affect surface conditions in an ombrogenous mire. However, as has long been recognised, it can be difficult to disentangle climatic effects from other, especially autogenic, processes. Empirical assessments in the changes in surface character and wetness in an ombrogenous mire, and their likely causation, really require consideration of three-dimensional changes of the local mire surface with time (*e.g.* Boatman, 1983); Hendon & Charman (2004) have presented testate amoeba data from only two cores, both from the same proximate topographical habitat, and macrofossil data from just one.

4.2.5 *Mire ontogenesis*

The peat core analysis described by Yeloff *et al.* (2007) indicates that, at least in the north-eastern part of Butterburn Flow, ombrotrophic bog peat was forming at least 4500 years ago. The great depth (a further 4 m) of peat deposits beneath their radiocarbon-dated sample suggests that peat formation in this location began much earlier, perhaps soon after the end of the last (Devensian) glaciation.

From the 2020 *NVC* vegetation map (see Figure 2) there appear to be at least two, possibly three, main areas of M18 bog vegetation separated from each other by streams. M18 is considered by many workers to mark out the regions of deepest (and wettest) peat in blanket and raised bogs (see discussion in Main Text). The topographic profile of the underlying mineral ground provided by Hendon & Charman (2004) may be suggestive of a shallow trough or basin, but their sections represent such a small proportion of the mire as a whole, it is not possible to make much further generalisation. However, it seems likely that some of the higher areas of peat at the west end of the site, such as the topographical 'peninsula' of the peat-covered Calf Hill, may be associated with sub-surface topographical variation in the buried Till (which in places protrudes above the level of peat in parts of this area). Overall, it seems most likely that, as with nearby sites for which sub-surface topographical data are available, the peatland has developed across a series of shallow troughs, depressions and ridges (and possibly small drumlins). However, additional peat depth profiles and peat macrofossil studies would be required to provide a more detailed understanding of how mire development was initiated at Butterburn Flow.

4.3 Coom Rigg Moss

4.3.1 *Topographical context*

Coom Rigg Moss (NY 690 795) is an area of peatland some 94 ha in extent, situated in a watershed location in which the main area of peat is roughly encompassed by the 320 m contour, except in the lower western arm. The Moss is partly bounded by somewhat higher ground on all sides. The northern side is bounded by the rising slopes of Coom Rigg, which reach 337 m aOD. In the north-west corner, it is overlooked by Little Samuel's Crags; in the north-east corner there is very slightly higher ground associated with the western end of the west–east trending Archy's Rigg; in the south-east corner is Rottenshaw Pike (325 m aOD) and in the south-west, Muckle Samuel's Crags (335 m aOD) and the slopes to the east of these. Drainage occurs through gaps between these higher areas, with outflows to the north-east, east, south-east, south-west and the north-west. Drainage from the south of the site forms part of the Irthing catchment, and flows into the Solway. Most other outflows feed into the Chirdon Burn, alongside Coom Rigg and thence to the North Tyne.

4.3.2 *Geological context*

The bedrock beneath and around Coom Rigg Moss has been mapped as Tyne Limestone Formation, which here is quite heavily faulted. Two WSW–ENE-trending faults are mapped in the vicinity of the Moss, one along the southern base of Coom Rigg and along the northern edge of the Moss, the other less exactly along the southern edge of the NNR (but not along the edge of the peat as mapped). North of the northern fault, two un-named bands of limestone have been mapped as part of the Tyne Limestone Formation, and are effectively truncated at the northern edge of the Moss. The topographical feature of Little Samuel's Crags is formed from a named exposure of sandstone (Seven Linns Sandstone), whilst Rottenshaw Pike is an exposure of the slightly younger Spy Rigg Sandstone. Elsewhere the rocks are covered by superficial deposits. Till is widespread around (and probably beneath) the Moss; thicknesses of more than 10 m of a grey boulder clay have been reported near Paddaburn (about 5 km west of the site) (Day, 1970). Peat covers the main area of the Moss, but also extends considerably beyond it, except along its northern side, mostly along shallow troughs and depressions with a broadly SW–NE orientation. The peat of the Moss is of variable depth, up to almost 10 m depth in a few places; the peat around it, which has largely been afforested, is likely to be thinner and more easily drained, but no data are available. Where peat is absent, Till of unproved thickness forms the surface deposit (except at Little Samuel's Crag and Rottenshaw Pike where Drift is absent). It was described as a "stiff boulder clay" by Chapman (1965), who considered that it underlaid the peat across the entire site, thereby making it 'watertight', but it is not clear how well attested this is. Any Till beneath the peat is likely to thin where the edges of the mire abut upon the sandstone outcrops, and this may be particularly relevant along the western side, below Little Samuel's Crags.

4.3.3 Peat infill and characteristics

Coom Rigg Moss has been examined in detail by Chapman (1964a, b; 1965; Chapman & Rose, 1991). This work included an assessment of the surface and sub-surface topography, and of peat stratigraphy, which provided an opportunity to establish the pattern of development of the mire. Chapman (1964a) found that the mire surface was underlain by "a ridge running to ESE between Little Samuel's Crags and Rottenshaw Pike with a second ridge running north to south between this first ridge and the higher ground to the north of the bog. Small valleys run away from these ridges to the east, south-west and the north-west", with the area east of the ridges draining both to the east and north-east. These valleyheads were of variable character, but included hollows and low areas and, in the north-east and south-west examples, depressions which Chapman regarded as basins. The sub-surface topography provided Chapman (1965) with a basis for sub-dividing the site into five catchment areas.

As might be expected in a site with a variable sub-surface topography, mire development was fairly complex. However, Chapman (1964a) recognised two main developmental pathways, intergrading spatially. The first "shows a sequence of fen peat, brushwood peat and *Sphagnum–Eriophorum* peat and may be called a 'raised bog' profile". It occurred in some of the less well-drained hollows. The fen peat contained monocots, including *Phragmites australis* and was underlain in most hollows by a "sticky dark brownish grey clay containing sand grains". The origin of this was not discussed by Chapman, but it seems to have been different from the 'stiff boulder clay' that was said to underlie to peat at the site (Chapman, 1965). The upper part of the profile, above the brushwood peat, consisted of a variable thickness of *Sphagnum–Eriophorum* peat which contained "the same species that form the present bog surface (*Sphagnum papillosum, S. magellanicum, S. imbricatum* and *S. acutifolium*). Macroscopic remains of *Eriophorum vaginatum, E. angustifolium* and ericoids are common". The transition of this peat with the brushwood peat was marked by an increase in humification and of ericoid remains. Some samples of the peat types and transitions were dated by pollen analysis, which suggest that the basal *Phragmites* peat dated to Zone VI and the basal brushwood peat to VIIa[1]. The transition of brushwood peat to *Sphagnum–Eriophorum* peat was also VIIa.

"The second type of profile consists of up to 3 m of *Sphagnum–Eriophorum* peat lying directly upon glacial drift. This peat increases in humification down the profile and the basal peat is dry, stiff and highly humified. In the profiles of this type the change from a lower more humified peat to the upper fresh peat is gradual and indefinite in level" (Chapman, 1964a). This profile was particularly associated with the buried ridges.

[1] The transition between Pollen Zones VI and VIIa is generally taken to be dated to around 5500 BC.

4.3.4 Developmental pathways

With respect to the two types of profile described above, Chapman (1964a) considered that "The first … is typical of raised bog development, showing a succession from open water to fen and finally to *Sphagnum* bog and being governed by both climatic and topographic factors. The second type of profile is that shown by areas of blanket bog and is essentially climatic in origin, though at Coom Rigg, the impeding of drainage by the basin peat may have been partly responsible". However, from the stratigraphical and macrofossil data provided by Chapman, there is little evidence for a significant phase of open water in the hollows, beyond perhaps some shallow pools, reflecting the apparent scarcity of well-defined or deep enclosed basins. It seems more likely that much of the succession in the hollows was primarily, as on the slopes and ridges, by paludification, not by terrestrialisation, and that the driving difference between the two types of seres was primarily topographical – poorly-drained hollows *versus* water-shedding ridges. For this same reason, it seems likely that the development of peat onto and across the ridges may have been more dependent on the accumulation of peat on the slopes and depressions below them than Chapman implies, perhaps as part of a progressive process of paludification from the hollows, depressions and valleyheads onto the higher ground. However, the relationship between peat initiation and development across the ridges and that in the hollows is not really known. Chapman (1964a) implied that events on the ridges might be separate from the on-going accumulation in the hollows, but his evidence for this is not clear[1]. On the other hand, it seems that the development of a fairly deep peat across the ridges may somehow be associated with peat accumulation in the basins, if only because some of the 'ridges' on the site have but a thinnish peat cover, despite being not obviously steeper than some of those with a deeper peat.

Both of Chapman's developmental pathways resulted in a fresh, poorly-humified *Sphagnum–Eriophorum* peat. Chapman (1964a) commented that "The most striking feature of the vegetation of Coom Rigg is the extreme uniformity in appearance of the bog surface", which is taken to imply that there was no obvious difference in the vegetation over the deeper peat of the hollows and that across the ridges. Apart from the occurrence of *Molinia*-rich vegetation near the edges, the main vegetational distinction he reported was the occurrence of a vegetation that was particularly rich in *Sphagnum magellanicum* at and near the north-eastern and south-western outflows. He attributed this to funnelling and greater water flow and found some evidence for enhanced productivity of both *S. magellanicum* and *S. papillosum* in one of these locations (Chapman, 1965). There was also some evidence for slightly greater exchange capacity and concentration of exchangeable bases, which he attributed to a flow-induced enhancement of 'mineral supply'.

4.3.5 Vegetation change

Chapman (1964a) sampled the vegetation of Coom Rigg Moss but reported this information in a semi-processed form, not as species tables. However, it seems clear that the vegetation over most of the Moss was referable to M18, with much *Andromeda polifolia, Sphagnum papillosum* and *S. magellanicum.* Hummocks of *Sphagnum imbricatum* and *S. fuscum* also occurred but were more scarce. In the soakway areas (his Site 2), *S. magellanicum* was more prominent than *S. papillosum* and it is possible that this expression of the vegetation had affinities to M21, but this cannot be assessed from the data available.

Much of the area around Coom Rigg Moss was afforested in the mid-1950s. These areas, and the outflows from the mire, were modified by drainage associated with afforestation. In addition, a

[1] Chapman (1964a) asserted that "peat formation was occurring over the whole of the present Coom Rigg Moss area by the beginning of Zone VIIb by which time sufficient *Sphagnum–Eriophorum* peat had accumulated in the hollows to produce about 80 cm when compressed by later deposits", but the evidence for this is not apparent from the data provided.

drain was dug along the eastern side of the main area of Moss, thereby separating it to some degree from its surrounding peatland. This drain appears to have been in place when Chapman did his original research between 1956 and 1959.

The vegetation of the site was re-surveyed in 1986, using the same methods as before (Chapman & Rose, 1991). On this occasion they recognised three main types of vegetation, dominated by *Deschampsia flexuosa* (mainly around and near the western margins), *Calluna vulgaris* (especially on the shallower peats over the NW–SE-trending buried ridge, and *Eriophorum vaginatum* (mostly on the north-eastern half of the Moss, where it was mainly over deep peat but on varying slope). The cottongrass (*Eriophorum*) vegetation provided the closest approximation to the former "*Sphagnum* carpet" that had covered most of the Moss in 1958. Overall there had been, amongst other things, a very considerable reduction in the frequency of some typical bog species, such as *Sphagnum papillosum* and *Andromeda polifolia*, a small reduction in *Calluna,* a complete loss of *S. imbricatum*, a substantial increase in *D. flexuosa* and a smaller increase in *Molinia caerulea.* There had also "been a loss of the shallower pools over the deeper area of peat" and "a switch from relatively uniform vegetation varying little with slope and peat depth, to one where these factors appear to have become more important in controlling the vegetation" (Chapman & Rose, 1991). Aerial photographs from 2003 and 2009 suggest that the main area of 'better' bog vegetation had become restricted largely to the north-eastern part of the site, but its current condition is not known (to us).

Chapman & Rose suggested that land-use changes on the bog associated with afforestation, such as a reduction of grazing, might help explain the vegetation changes they observed. They seemed reluctant to recognise that hydrological change might be important, because "the central area of Coom Rigg is a shedding system, dependent upon precipitation for its water supply (Chapman 1965), hence afforestation should only be expected to affect the peripheral regions of the bog". In many forestry contexts this proposition may hold good, but it seems very likely that the unusual and varied topography of Coom Rigg Moss, with a decline of the peat surface by some 6 m from the highest point to the NW outflow and of 11 m to the SW outflow, the latter over a distance of less than 400 m, may have rendered this site more sensitive to enhanced drainage in its surroundings, and on its surface, than might normally have been expected. In addition, the possibility of some hydraulic connection between the peat water and that of the bedrock cannot entirely be discounted, at least near the margins and especially in the vicinity of Little Samuel's Crags.

Unfortunately, neither measured water table data nor quadrat records appear to be available from the site, nor do we have details of drainage activities on and near the Moss. The development of a strip of vegetation with much *D. flexuosa* along much of the western side of the Moss by the time of Chapman & Rose's re-survey seems, at first sight, more likely to be a consequence of drying than of lack of sheep grazing, but without quadrat data on vegetation composition, it is difficult to make informed comment. If any drying had occurred by the time of Chapman & Rose's re-survey, then the areas least affected would seem to be the north-east sector of the mire and the bottom of the 'deep' south-west valley from which they still recorded *Carex paupercula.* As this valley is thought to be a focus of drainage from some other parts of the mire, it might be expected to be less affected by lowering water tables than some of the other, higher, western areas.

Hendon, Charman & Kent (2001) reconstructed former water tables at Coom Rigg Moss based on an analysis of testate amoebae and using a radiocarbon-based chronology. They examined four cores along a north–south section towards the eastern side of the mire (*i.e.* in an area considered by Chapman & Rose to be least affected by vegetation change); two (I and IV) were close together, near the centre of the section, the others were near the margins at its ends, and on shallower peat. In essence, they found a significant pattern of inferred water table change since AD 500, which was broadly similar in all four cores. There was also considerable coincidence in the overall patterns of inferred water table change between the cores from Coom Rigg Moss and the (nearby) Butterburn Flow, and the authors considered that this was most likely to be attributable to climatic change.

In general, the fluctuations in inferred water table were generally sharper or of greater amplitude in the two marginal locations, especially in the southern 'margin' site (II). However, the most recent inferred change observed was a drop in water tables, "in the early to mid-twentieth century", which was as sharp, or sharper, in the two cores from the mire 'centre', especially in core I. Hendon & Charman (2004) offered a further reconstruction of water tables for the 'central' sites I and IV, for the period 1750–2000, based on their 2001 data with a modified chronological basis. In this, water levels suggested by the two cores were similar and stable during the 19th century at about 4 cm bgl[1], but declined during the 20th. In one core (I) a low value of about 8 cm bgl was suggested for 1950, followed by some recovery to about 5 cm bgl; the other showed a more gradual but sustained fall during the 20th century. The final (2000) value for both cores was similar, at about 7 cm bgl, suggesting a lowering by about 3 cm since the 19th century (Hendon & Charman suggested a maximum reduction of 4.5 cm). These results are not readily reconciled with the observations of a healthy *Sphagnum* surface in the late 1950s (Chapman, 1964a) followed by significant, and seemingly rapid, 'deterioration' by 1986.

4.3.6 Mire ontogenesis

Topographically, Coom Rigg Moss is a rather complex site. It may also be unusual, but this is difficult to assess because few comparable peatlands have the wealth of topographical detail, particularly of sub-surface topography, that was provided for Coom Rigg Moss by Chapman (1964a).

Essentially, the sub-surface (base of peat) topography has identified two sub-surface ridges which merge south-eastwards and separate four main hollows with deeper peat. These depressions effectively form valleyheads that drain north-east, east, south-west and north-west, with the ridges forming a watershed. The entire site itself also occupies a perched, watershed location, with slightly higher ground around parts of the Moss, breached by the four main valleyheads and by some outflows along the southern margin.

Both the ridges and depression at the site are largely covered with ombrogenous peat which forms an extensive shallow 'dome', elongated north–south, partly, but not entirely along the axes of the buried ridges. In 1958 the vegetation across the entire ombrogenous surface was surprisingly uniform and seems to have consisted of a *Sphagnum*-rich community referable to what is now known as M18. The surface was then "extremely regular in appearance consisting of a very even *Sphagnum* carpet. The few pools which occur on the surface vary from 10 to 20 cm in depth and are not much more than 1 m in width. These pools are restricted to the central part of the bog where the slope does not exceed about 1.5°. Measurements of the orientation of forty pools showed that their long axes were generally at right-angles to the slope of the bog surface." (Chapman, 1964a). The 'dome' of peat, partly confined by slightly higher adjoining ground, was (and, one assumes, still is) clearly a 'Domed Ombrogenous Surface' (WETMEC 1 of Wheeler, Shaw & Tanner (2009)), and has strong affinities to the surfaces of sites elsewhere referred to as 'raised bogs'. One difference, however, is that tongues of (ombrogenous?) peat extend downslope from the main bog 'dome' into the four main valleyheads, and these have some topographical affinities with 'valleyhead mires'. Chapman (1964a) commented that this was particularly the case along the part of the eastern margin of the bog where *Phragmites* peat had persisted for much longer than elsewhere and where some depauperate plants of *Phragmites* still persisted on the mire surface and which was "in many ways similar to valley bog systems more often found in lowland areas". But a similar comment may also be made about the other outflow arms, especially the deep south-western arm which had a greater proportion of *S. magellanicum* than did the main bog surface, and also had *Carex magellanica* and *Drosera anglica*, both apparently restricted to this area.

[1] These water table values have been estimated from a figure provided by Hendon & Charman (2004) and are subject to the constraints of this procedure.

Chapman (1964a) recognised that only a couple of hollows could be regarded as true 'basins' and even in these locations the area and depth of closed depression was small, so whilst the hollows were doubtless poorly-drained, they are likely to have contained little standing water, and that is likely to have been shallow. Most of the bottoms and lower slopes of the hollows are lined with a 'soft sandy clay', of un-established provenance, perhaps most probably downwash or solifluction material from the adjoining slopes. Although Chapman considered that the seral development of the hollows started with open water, there is little evidence from stratigraphy or macrofossils that significant areas of open water once occurred, and much peat initiation and accumulation seems to have taken place on a poorly-drained surface rather than by terrestrialisation. In most cases, in the hollows, the earliest peat, initiated in pollen zone VI, was a 'fen' peat, with much *Phragmites*, suggesting relatively base-rich conditions (possibly provided in part by the 'soft sandy clay'). In most instances this was succeeded by brushwood (alder–birch) peat, but in some of the hollows (mostly those without a sandy clay) wet woodland seems to have been the primary colonist of the mineral ground, whilst in one instance (where *Phragmites* peat comes close to the surface) it seems to have been absent altogether. In the hollows, the lower minerotrophic peats were replaced by ombrotrophic peat in pollen zone VIIa and this was considered by Chapman to be "almost contemporaneous" across the whole bog. Chapman regarded this sequence as a 'raised bog' succession, because it started from open water (?) and fen, but there is no evidence, or much reason to suppose, that small 'raised bog' domes of ombrogenous peat formed in the hollows. The accumulation of peat within the hollows appears to be a consequence of deteriorating drainage and paludification, and the transition to ombrogenous peat reflects a reduced inflow of minerotrophic water from the margins into the more central peat areas, and also an increase in precipitation amounts. As Chapman suggested, the location where *Phragmites* persisted longest is that where run-off from the adjoining 'valley' slopes may have particularly sustained and significant (Chapman, 1964b).

The ridges appear to have been colonised initially either by wood peat, which formed only a thin layer before being replaced by ombrogenous peat, or directly by ombrogenous peat – though even in this latter case there must, almost by definition, have been a precursor minerotrophic surface of some sort prior to ombrotrophication. [Unfortunately, Chapman (1964a) did not provide a detailed macrofossil profile from the ridges.] The basal *Sphagnum–Eriophorum* peat (apparently from the ridges) was dated at pollen zones VIIa and VIIa/VIIb transition. He observed that the basal peat was "dry, stiff and highly humified" and became progressively fresher upwards, and the fresh *Sphagnum–Eriophorum* peat came to form part of a single surface unit with that of the peat sequences in the depressions.

The peat and vegetation that ultimately developed over the ridges seems to have been essentially the same in character and composition as that which formed the top of the developmental sequence in most of the hollows, despite their somewhat different ontogenic pathways. This provides a good example of the formation of a single possible 'climax condition' as a result of the convergence of the two seres. The main 'dome' of the Moss cannot really be considered to be a complex of mire forms resulting from their different starting topography, but it essentially constitutes an overarching, single domed unit, though somewhat 'frayed' at the edges.

4.3.7 Implications for mire characterisation and typology

Although some of the marginal details of the peat surface at Coom Rigg Moss reflect the variable sub-surface topography, the main central area of peat is slightly domed and has a similar appearance across both former hollows and ridges. It also has similar characteristics, and probably similar hydrodynamics, to those of 'domed ombrogenous surfaces' (WETMEC 1 of Wheeler *et al*. 2009) that occur in lowland ombrogenous bogs. However, its topographical context and ontogenesis is strikingly different from that of certain lowland examples of WETMEC 1, especially those which have developed from over 'flat' coastal plains or lake basins. Wheeler *et al.* 2009 recognised that, in the lowlands, essentially the same 'domed ombrogenous surface' could occur in a variety of topographical contexts and regarded them all as examples of WETMEC 1, but proposed an informal subdivision of this into 'ontogenic types'. The example at Coom Rigg Moss would be referable to 'Ontogenic Type 4: Bogs on irregular terrain' within WETMEC 1.

Moore & Bellamy (1974) designated mires such as Coom Rigg Moss as 'Ridge Raised Mires' in which peats from basins had coalesced across ridges or expanded into peat that had already started to form there. The topography of Coom Rigg Moss is clearly associated with a ridge, but, as Chapman's sections show, the mounded peat surface is not exclusively associated with this, nor does the peat surface generally conform much with the sub-surface topography, except in a few marginal locations where variation in this is extreme.

Whether one wishes to call sites such as Coom Rigg Moss a 'ridge-raised mire' or just a 'raised mire' seems to be largely a matter of personal preference. However, it is clear that if it is to be designated as a 'ridge-raised mire' then, for consistency, a large number of other bogs in lowland England and Wales that are often considered to be 'raised mires' (*e.g.* in the *NPRI* – Lindsay & Immirzi, 1996) must also be designated as 'ridge-raised mires', because they have also developed over irregular terrain by essentially the same processes as at Coom Rigg Moss. Wheeler *et al.* (2009) observed that "examples of bogs that have developed across ridges and mounds are provided by some of the large mosses bordering the Solway estuary, Cumbria (Bowness Common, Glasson Moss, Wedholme Flow)… Many of the large mosses on the Till plains of West Lancashire have also developed by this process, along with others on fluvioglacial sands and gravels (such as Rixton and Risley Mosses). The precise character of the underlying topography varies considerably between and within sites. In some instances the sub-peat topography is rather subdued; in some, the underlying surface may have an overall slope to varying degrees (such as Rixton and Risley Mosses) (Leah *et al.,* 1997); in yet others, peat expansion has occurred from within deep depressions embedded within the plains (such as Chat Moss) (Birks, 1965; Hall *et al.*, 1995).". Likewise, Taylor (1983) had previously commented that raised mires with "some resemblance to the classical *Hochmoore* [of continental authors]… rarely occur in England and Wales. Even in Ireland (except for the central plain) and Scotland, as far as the present author knows, well-defined cupolas of ombrogenous peat are partly a reflection of the underlying topography". It is, of course, quite possible, as Wheeler *et al.* (2009) pointed out, that the capacity of ombrogenous peat in basins to coalesce across ridges "is partly dependent upon climatic circumstances, and one might expect that in wetter, cooler regions Type 4 bogs[1] can form over greater irregularities in terrain". Whether this is a sufficient or desirable basis to distinguish them is a moot point and a probable focus for on-going, sterile debate, whereas they may be united by the common possession of a 'domed ombrogenous surface' (WETMEC 1 of Wheeler *et al,* 2009).

It should be recognised that, because of the similarities of their surfaces, the identification of a bog as a raised bog or a ridge-raised bog requires some examination of its sub-surface topography, to avoid its status being given largely arbitrarily depending whether or not its sub-surface topography has been examined!

It should also be recognised that if Coom Rigg Moss had been examined at a much earlier date, say sometime in pollen zone VIIa, Mesolithic telmatologists may perhaps have justifiably distinguished two separate WETMECs, one relating to peat development on water-shedding ridges, the other to peat accumulating in poorly-drained hollows. Some other upland mire sites in Britain may still perhaps be in this state and form a mire complex. Here the assumption is made that, particularly for the purposes of conservation management of sites, attention should be focussed upon what they have become, not on their former ontogenic status.

[1] Ontogenic Type 4: Bogs on irregular terrain (of Wheeler *et al.*, 2009)

4.4 Foalstand Rigg Mire

Foalstand Rigg is situated at NGR: NY 6220 7180, and covers a large area of about 65 ha, about 1 km to the north of the main MoD site at Spadeadam. A small section of the mire comprises unit 3 of Spadeadam Mires SSSI (Figure 3). Foalstand Rigg mire is connected to an unnamed mire to the north and north-west, which remains under mature conifer plantation.

Prior to forest clearance work between 2002 and 2009, most of Foalstand Rigg mire was covered with planted conifers and intensively furrowed. Restoration works involved partial forest clearance and blocking ditches, but because of the depth of peat and wet mire surface, large areas of conifers could not be felled. Consequently, much of the mire remains covered by almost impenetrable partially fallen spruce trees, and conifer regeneration is an on-going problem across the mire (Eades & Shaw, 2018). Whilst there are few large ditches on Foalstand Rigg mire, the northern mire supports many active drains.

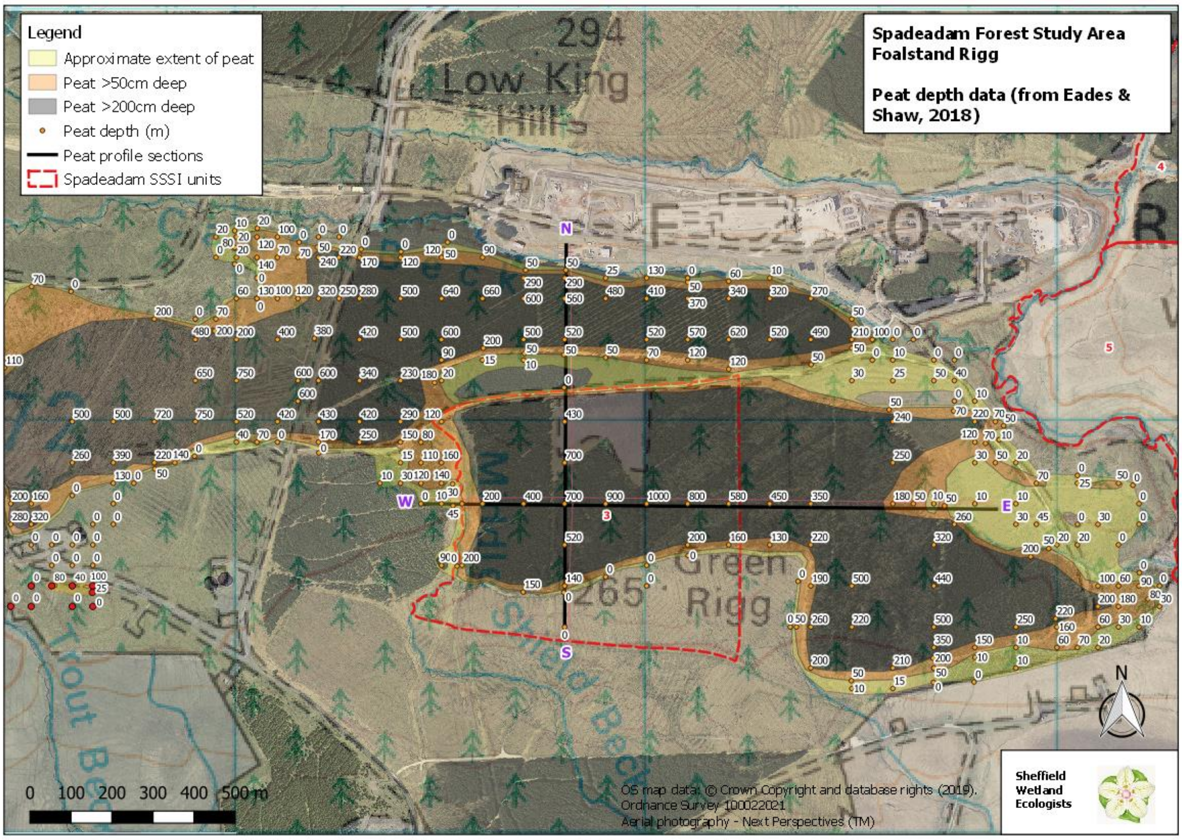


Figure 3. Foalstand Rigg Mire: peat depths & section locations (Eades & Shaw, 2018).

4.4.1 Topographical context

Foalstand Rigg mire is a broad area of peatland, much of the surface of which lies at about 260 m aOD, dropping to about 250 m aOD at the western and eastern ends. It is roughly 1.5 km long west-to-east and 0.5 km wide north-to-south, with a large lobe extending to the south-east. The eastern half of the mire encompasses an area known as Jock's Flat. The western edge of the mire is marked by the southward-flowing Middle Shield Beck, while the eastern end is delimited by steep mineral ground dropping down to the south-eastward flowing King Water. The southern edge is constrained by a shallow ridge of mineral ground (Green Rigg) which then drops steeply away to the south, towards Middle-Shield Rigg and Kingturn Rigg. A prominent lagg is present along much of the southern edge of Foalstand Rigg mire, gradually coalescing into a small stream that flows westward to join Middle Shield Beck. Jock's Flat Sike bisects the south-eastern lobe, flowing south-east to join the King Water; a small stream also flows from the western corner of the south-eastern peat lobe, flowing south-eastwards to meet the King Water close to Kingturn Rigg. The northern boundary of the mire is marked out by a forestry access track that runs at the base of another shallow ridge of mineral ground (Foalstand Rigg), which rises above the peat at its western end, but subsides beneath shallow peat to the east. This forms the southern edge of another (unnamed) body of deep peat immediately to the north of Foalstand Rigg, which stretches westwards almost to the boundary with Prior Lancy (see Section 4.7). Caud Beck marks the northern edge of this unnamed peatland, which is entirely beneath mature conifer plantation.

4.4.2 Geological context

BGS mapping shows that most of Foalstand Rigg mire and the unnamed northern peatland are underlain by mudstones and sandstones of the Fell Sandstone Formation, with several narrow north-east to south-west trending bands of limestone (Jerrycalf Limestone, Desoglin Limestone, and Clattering Band Limestone) crossing the eastern half of Foastand Rigg mire. The BGS also map Foalstand Rigg mire and the unnamed northern peatland as a single body of Peat, whilst a layer of Till is mapped as covering the bedrock surrounding the Peat, and Till is likely to underly the peat deposit itself.

4.4.3 Vegetation

Jerram & Adams (1991) described Foalstand Rigg mire as a small remnant of a much larger 'blanket mire' that had been completely afforested apart from a small area about 5 ha in extent near to the north-west corner of the mire. They considered the remaining mire vegetation to be of high quality and recommended future detailed quadrat survey.

A subsequent site visit by Henry Adams and two English Nature conservation officers in 1992 provided further detail (English Nature, 1992). The main area of open mire was described as **M18a** *Erica tetralix–Sphagnum papillosum* raised and blanket mire, *Sphagnum magellanicum–Andromeda polifolia* sub-community.

The open mire supported a number of higher plants including *Andromeda polifolia, Calluna vulgaris, Erica tetralix, Eriophorum angustifolium, Eriophorum vaginatum, Vaccinium oxycoccos;* and a variety of bryophytes such as *Aulacomnium palustre, Pleurozium schreberi, Polytrichum alpestre, Polytrichum commune, Rhytidiadelphus loreus, Sphagnum capillifolium, S. cuspidatum, S. magellanicum, S. recurvum,* and *S. tenellum*.

They also noted a band of *Molinia* approximately 20 m wide adjacent to the forest road on the northern edge of the mire, and at the southern edge of the mire the mineral ridge (Green Rigg) also supported a good flora of *Sphagnum* bog-mosses. Overall, the surveyors noted that much good quality mire had been afforested, including Jock's Flat to the east, and they considered it likely that it could revert to good quality open mire if the trees were felled.

4.4.4 Peat infill and characteristics

An early peat depth survey by Burlton (2006) was aimed at mapping the extent of peat greater than 2 metres in depth for the Forestry Commission. A 2018 peat depth survey of Foalstand Rigg (Eades & Shaw, 2018) closely agreed with the 2-metre peat depth boundary of Burlton, but also showed extensive areas of peat between 0.5 m and 2 m depth to the east, and to a lesser extent to the west (Figure 3). Within the main body of the mire the deepest peat was found in the western part, reaching 10 m on the edge of the afforested zone, and a large proportion of Foalstand Rigg was deeper than 4 m. Most of the bog surface remains very wet despite the damage caused by afforestation (Eades & Shaw, 2018).

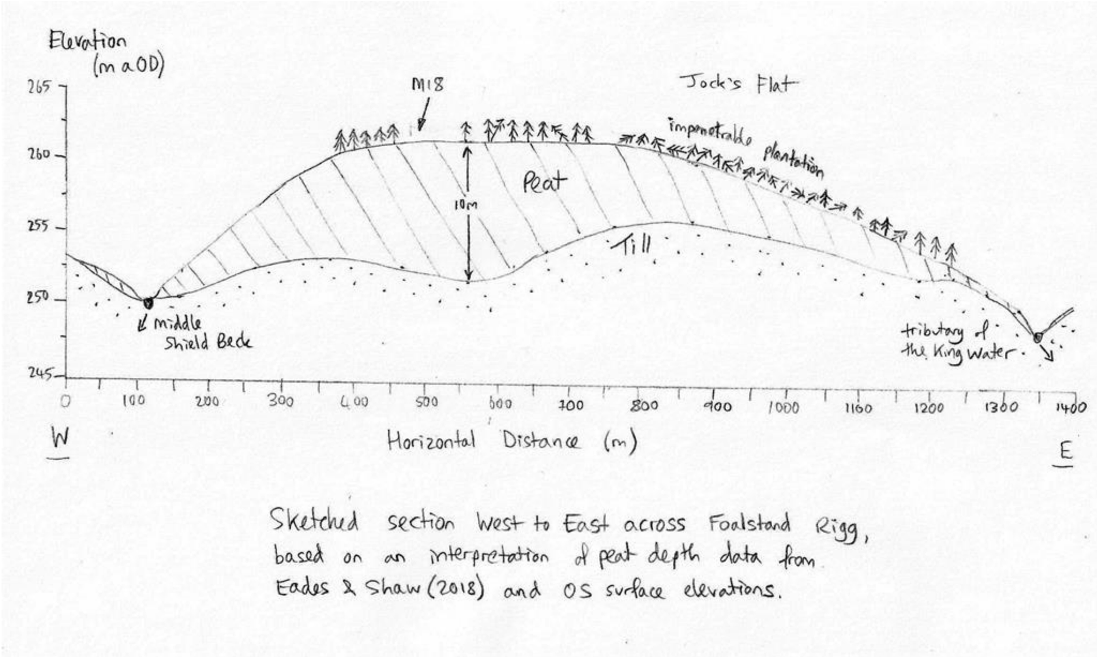
The unnamed afforested northern bog that was also sampled by Eades & Shaw (2018), though narrower than Foalstand Rigg mire for much of its length, also supported extensive deep peat, much of it over 4 m, and reaching a maximum of 7.5 m toward the western end. The narrower sections in particular were quite dry at the surface, but the broader western part of this mire remains very wet.

4.4.5 Mire ontogenesis

Sections along and across the main axis of Foalstand Rigg mire have been sketched using the peat depth data of Eades & Shaw (2018) (Figure 4). Although the surface contours have not been levelled, the surface topography of the mire has been estimated based on a combination of mapped OS contours and personal site knowledge.

Despite the lack of accurate surface elevation data, these sections suggest that the deepest peat of Foalstand Rigg mire has developed in a broad, shallow depression within in an undulating trough between two low ridges to north and south, with a further long trough-like peat-filled depression or 'shelf' to the north and north-west. The south-eastern lobe of Foalstand Rigg mire may also have originated in a shallow depression towards its south-western side, as the peat reaches a depth of around 5 m there.

The lack of peat stratigraphic information precludes any knowledge of surface conditions at the onset of mire development. However, as with both Prior Lancy mire (see Section 4.7) and Long Moss (see Section 4.6), the configuration of the underlying terrain is suggestive of paludification rather than the terrestrialisation of an extensive water-filled basin, though the initial occurrence of localised, shallow water bodies within hollows cannot be discounted.



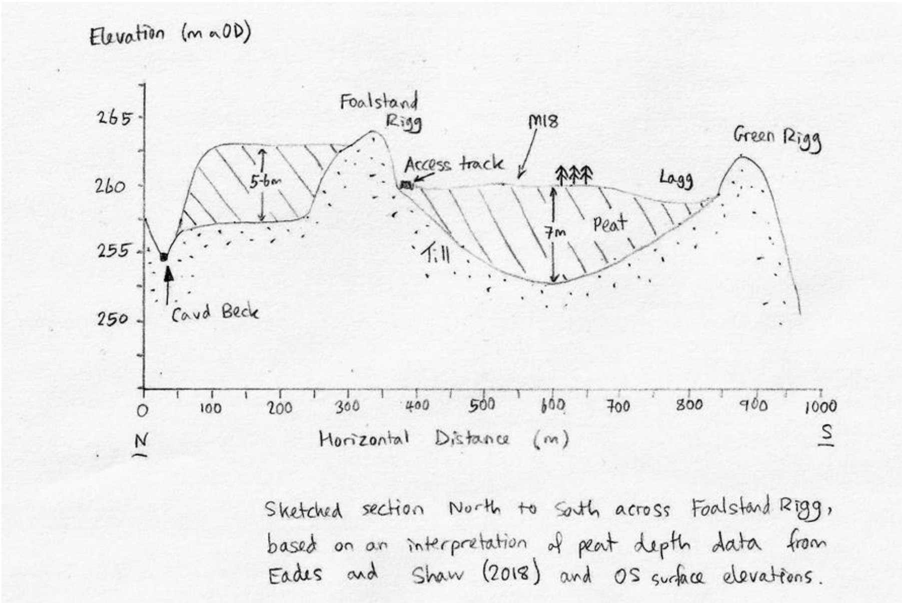


Figure 4. Sections across Foalstand Rigg Moss: a) west–east; b) north–south.

4.5 Hummell Knowe Moss

Hummell Knowe Moss (Figure 5, centre at around NGR: NY 7015 7130) is a largely ombrogenous mire located a short distance (about 0.6 km) north-east of the north-east end of The Wou (see Section 4.10), and separated from this by a low hill. Its northern margin is mostly bordered by conifer plantation and the western-most end has been heavily ditched. These drains were apparently being blocked in 2018 (O'Reilly, 2019). The main area of mire, as mapped by Natural England, forms an elongated unit, aligned just to the north of west–east, and has a length of about 1.75 km and a width (north–south) of between about 0.3–0.8 km. Its total area is about 65.4 ha, but peat (as mapped by BGS) extends well beyond the eastern limit of the mapped area of mire. The peatland can be divided into east–west units of unequal size by a small, north-flowing watercourse of uncertain origin (Figure 5). These two units may represent ontogenically separate mires. The larger eastern unit was examined by the British Ecological Society *Mires Research Group* in 1978 and some of their results were subsequently published (Clymo, 1980). Note that the two units recognised here do not correspond with the units A and B mapped by Natural England, which relate to units north and south of a fence line across the eastern unit of the mire. Their relationship to four sub-units recognised by O'Reilly (2019) is shown in Figure 5.

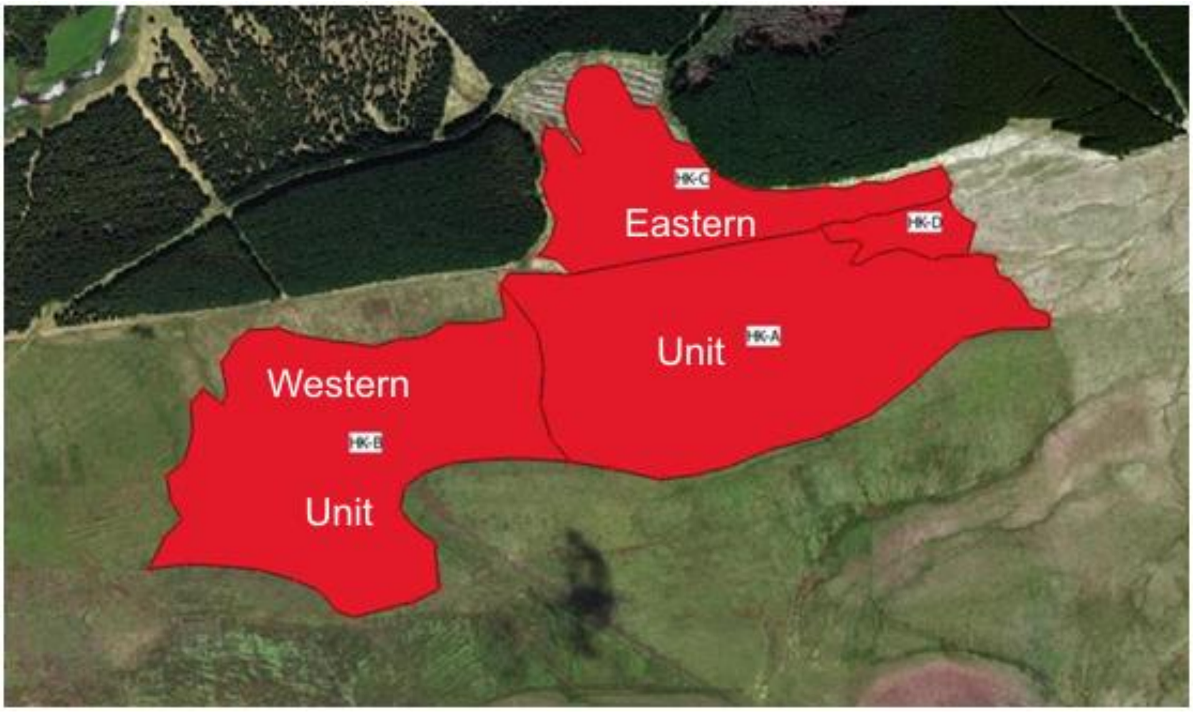


Figure 5. Sub-sites of Hummell Knowe Moss (reproduced from O'Reilly, 2019), in relation to the 'Eastern' and 'Western' Units referred to in the text.

4.5.1 Topographical context

Hummell Knowe Moss occupies one or more basins in a partial watershed location on an interfluve between the River Irthing and Tipalt Burn, both of which flow south or south-westwards. The interfluve ridge curves broadly south-westwards from Black Fell to Thirlwall Common (north side) and contains a large number of areas of peatland, including The Wou, in addition to Hummell Knowe Moss. In the vicinity of Hummell Knowe Moss, the ridge is some 2.2 km wide, and the mire is aligned obliquely across much of its width. Much of the area of mire is encompassed within the

245 m contour, but at its eastern end peat slopes and drains down to the adjoining Hummellknowe Sike (a tributary stream of Tipalt Burn) at about 220 m aOD. On the northern side the mire is largely flanked by low hills, which include the afforested Hummell Knowe (265 m aOD) and Lamb Rigg (246 m aOD), and the mire margin extends northwards locally into an embayment formed between these. North of Hummell Knowe hill itself the spine of the interfluve rises gently to Black Fell, but more generally to the north-west of the site the ground falls north-westwards into the Irthing valley. In the north-west corner of the mapped mire (which includes the western unit and the north-western end of the eastern unit) the peat surface falls north-wards by some 5 m into a shallow valley formed along the south side of Lamb Rigg, whence water drains westwards along a straight drainage ditch, before flowing north-westwards along a more natural-looking drainage channel into the headwaters of the River Irthing.

Along much of its southern side, the mire margin is barely contained by the flanking mineral ground, which here (as Burndivot Common) slopes broadly southwards, down from the edge of the mire for some 0.75 km to the south-west-flowing Tipalt Burn. Towards the western end of the southern side, and mainly affecting the western unit, the mire is wrapped around the northern edge of another low hill (Hugh's Hill, 253 m aOD). Two further low hills (253 m and 258 m aOD (Burn Divot), south-west and west of the western unit, help to separate this from The Wou peatland.

4.5.2 Geological context

BGS mapping shows all of Hummell Knowe Moss, and much of its surroundings, to be underlain by mudstones, siltstones, sandstones and limestones of the Tyne Limestone Formation. South and south-west of the site several interleaved un-named bands of sandstone, also referable to the Tyne Limestone Formation, have been mapped. One of these has its north-eastward termination near Burn Divot and underlies the south-west corner of the mire; it is mapped at outcrop for much of its length. However, superficial deposits cover the bedrock elsewhere around the mire. Till is widespread, but there are also large areas of peat mapped, additional to that of Hummell Knowe Moss. North of Hummell Knowe hill and Lamb Rigg there is another elongate, north-east trending peat deposit which constitutes Scotchcoultard Waste (and is afforested), whilst to the south there is a north-east trending extension of Burndivot Moss, which extends across Burndivot Common. Till may well underlie all of these peat deposits, but this is not known.

4.5.3 Vegetation

Aspects of the vegetation of the eastern section of the site were examined by the *Mires Research Group* (Clymo, 1980). Recently, O'Reilly (2019) has made an *NVC* survey of the entire site. As part of his work, O'Reilly recognised (and mapped) some bespoke categories of mire vegetation, identifying an 'M18n' (from *Narthecium* runnels) and subdividing M20 into M20d (dry) and M20w (wet) units (Box 1).

The mire appears to be almost entirely ombrogenous in character. It contains two large patches of M18a, one in each unit, though the western end of M18a in the western unit has been dissected by drains, some of which are associated with weakly minerotrophic vegetation (M6). In the eastern unit, the M18 area is located fairly centrally, though is shifted slightly north of centre away from the southern rand and margin and extends to some extent into the embayment between Hummell Knowe and Lamb Rigg hills. This part of the site was described by Clymo (1980):

> "Hummell Knowe Moss has a central, slightly domed, bog plain about 0.5 km across with a nearly complete cover of *Sphagnum magellanicum*, and, in order of abundance, almost constant occurrence, in 25 x 25 cm quadrats, of *Eriophorum vaginatum, E. angustifolium, Erica tetralix, Narthecium ossifragum, Andromeda polifolia, Vaccinium oxycoccos, Drosera rotundifolia* and *Sphagnum tenellum*, with several other species nearly as common. This central area is wet, but with little open water, and is surprisingly free of the hummock and hollow topography, on a scale of about 5 m, which is usually characteristic of

such areas. (There are a few hummocks on the moss, not associated with pools, and these may turn out to be of unusual interest.)"

This assessment shows a curious mis-match with the description of Ratcliffe (1977), which stated that "*Sphagnum papillosum* is dominant throughout", but concurred in other respects, and noted that "*Andromeda polifolia* is remarkably abundant". Recently, O'Reilly (2019) has provided details of nine quadrat samples from the 'centre' of the site, and these show that both *S. magellanicum* and *S. papillosum* are widespread and locally abundant but that, in this data set, *S. papillosum* is the more frequent and generally the more abundant of the two.

In the western unit (not considered by Clymo), the M18 area is located more strongly towards the southern margin (*i.e.* away from the peat slope down into the north-western drainage ditch) and partly occupies the embayment between Hugh's Hill and Burn Divot.

Box 1. Bespoke categories of M18 and M20 vegetation recognised by, and taken from, O'Reilly (2019)

M18-n

These areas had a low (or no) cover of the typical M18 peat-building *Sphagnum* species: *S. magellanicum*, *S. papillosum* and *S. capillifolium*. There was a high cover of bog asphodel and the main *Sphagnum* species were usually *S. tenellum* and *S. cuspidatum*.

This type of M18 vegetation was not described in the *NVC*, but was clearly of conservation significance. It appeared to be a slightly soligenous type of M18 vegetation that developed in shallow surface flow tracks through more typical ombrogenous M18a vegetation. These areas supported white beak-sedge *Rhynchospora alba* and great sundew at HK-D at Hummel Knowe. More extensive areas of similar vegetation occurs on the nearby Butterburn Flow.

This M18-n vegetation had similarities to the M16c *Erica tetralix–Sphagnum compactum* wet heath: *Rhynchospora alba*/*Drosera intermedia* sub-community, the M17a *Trichophorum germanicum* (*Scirpus cespitosus*)*–Eriophorum vaginatum* blanket mire: *Drosera rotundifolia–Sphagnum* sub-community and the M21a *Narthecium ossifragum–Sphagnum papillosum* valley mire: *Rhynchospora alba–Sphagnum auriculatum* s.l. sub-community.

The constancy of hare's-tail cottongrass (a species more or less strictly confined to bog, rather than other types of mire habitat) in the M18-n here ruled out M16c and M21a, which both have mainly southern and eastern distributions in Britain. The M18-n also had more frequent bog rosemary and *Sphagnum cuspidatum* than M16c, M17a or M21a. Those three vegetation types all have constant purple moor-grass, which was lacking in the M18-n."

M20-d and M20-w

The 30 samples were sub-divided into drier M20-d and wetter M20-w forms of M20.

M20-w was the more distinctive of the two, having more frequent *Sphagnum fallax* and/or *Polytrichum commune*, often at relatively high cover, and to a lesser extent, more frequent *Sphagnum palustre* or *Sphagnum papillosum*. Similar vegetation is briefly described in Averis *et al*. (2004) and this is a relatively common type of bog vegetation in northern England. This type of M20 was transitional to poor-fen vegetation and many of the samples were from the lagg zone around bogs. There was often a relatively wide band of M20-w vegetation on sloppy ground before even wetter vegetation such as M6, M4 or M23 in the main lagg channel. More extreme forms of this vegetation with very high cover of *Sphagnum fallax* (with or without *Polytrichum commune*), were included within the M2b here.

The M20-d lacked, or had much less of the M20-w indicator species mentioned above. It was transitional to heath vegetation and had slightly more frequent wavy hair-grass, bilberry and pleurocarpous mosses such as *Pleurozium schreberi* and *Hypnum jutlandicum*, as well as the acrocarpous moss *Dicranum scoparium*. This is the most common type of M20 vegetation in northern England and is also briefly described in Averis *et al*. (2004).

Although many stands were clearly one or other of these two types of M20, the cut-off point for splitting them was arbitrary. Samples with more than 10% cover of *Sphagnum fallax*, *Sphagnum papillosum*, *Sphagnum palustre* and *Polytrichum commune* combined, were included in M20-w and the remaining samples included in M20-d.

The areas of M18a are very largely, but not completely, encircled by a band of M19 or M19a, of variable width but mostly quite narrow, which in most places forms a transition to M20. M20 vegetation is widespread across the mire, and in large measure occupies the surfaces that are not M18 or M19. It is particularly extensive on the slope between the M18a area in the western unit and the north-western drainage ditch; on the peat slopes between the M18a area in both units and the southern margin, particularly where this falls away from the mire; and on the east-sloping peat at the eastern end of the eastern unit; it also occupies the strip between the two main patches of M18a. O'Reilly (2019) regarded the areas of M19 and M20 (perhaps excluding M20w?) as 'rand'.

The eastern end of the eastern area of M18a has been partly fimbriated by a number of runnels and small gullies that flow, apparently as small erosion features, from the M18a area down the eastern slope, supporting narrow strips of vegetation that have been mapped variously as M19, M20w, M25a and M17; *Trichophorum*-rich vegetation forms a comb-like band around much of the eastern margin of the M18a. O'Reilly has also mapped a significant (about 8 ha) patch of 'M18n' vegetation in the north-eastern corner of the M18a area, and this appears to feed down into some of the runnels and gullies on the eastern slope. In places, mostly further down the eastern slope, water flow lines support vegetation mapped as M6, M23 and M25, embedded within a matrix of M20.

Along much of the northern margin of the eastern unit, below Hummell Knowe, the interface between M20 and the mineral ground is marked by a variable band of minerotrophic vegetation, including M6, M23 and M25, apparently forming a lagg-like strip below the rising mineral ground. By contrast, along much of the southern side of the eastern unit minerotrophic vegetation has been mapped mostly just as a very narrow and discontinuous strip of M6. However, minerotrophic vegetation is generally better developed along the southern margin of the western unit, below Hugh's Hill and Burn Divot and in the embayment between them. In O'Reilly's mapping, M20w (which he considered to be "transitional to poor-fen vegetation") was particularly extensive here. Of this area, Clymo (1980) had commented that "To the south-west is a distinctive region which may be flushed by water running off the low hills behind. This region is recognisable by tussocky *Eriophorum vaginatum* on which grow species such as *Potentilla erecta* which are not found elsewhere on the mire centre, though common on the surrounding mineral ground. Between the tussocks is an impoverished bog flora". This area of 'lagg' appears to source the weakly minerotrophic strips that penetrate the western ombrogenous area northwards along ditch lines. However, O'Reilly's mapping provides no floristic suggestion of similar weakly-minerotrophic conditions along the northward flow lines and drain that separate the eastern and western mire units, suggesting that drainage here may be very largely, or completely, endotelmic.

4.5.4 Peat infill and ontogenesis

With regard only to the eastern unit, Clymo (1980) reported that:

> "The surface is a roughly elliptical eccentric dome about 300 m by 600 m, the centre of which is ca 2 m higher than the edges. Around the perimeter the surface slopes more steeply into valleys to east, west and north. ... The bog has formed in a basin, which may run out in a valley to the north [*sic!*]. The southern edge seems to be particularly steep sided, with peat depth increasing from ca 3 m, to ca 10 m over not more than 100 m."

Much of the peat was 7 to 10 m deep. The deepest peat found was 10.7 m. These topographical and peat depth determinations, which were based on a grid with an interval of 100 paces, show no clear evidence of large sub-subsurface irregularities (such have been noted in a number of other nearby mires), but the basin appears to shallow towards the west, raising the possibility that the east and west mire units may occupy partly separate basins. The steep and substantial slope of peat along the southern side of the eastern unit appears to be a prominent rand that has apparently developed independently of the underlying topography.

The stratigraphy of the peat was examined at just one grid intersection, where the peat was 10.4 m deep. Here, Clymo (1980) reported:

> "Immediately above the basal clay is ca 2.5 m of *Phragmites* peat, with seeds of open water species such as *Nymphaea* and *Potamogeton*, and some remains of *Equisetum* and of a small leaved *Sphagnum* and of *Polytrichum*. Taken together these indicate a shallowing lake, probably tending to be acid. Above, there is a fairly sharp transition to amorphous peat with remains of *Eriophorum* and ericaceous roots. Nearer the surface the structure of *Sphagnum* is well preserved. The profile is remarkably similar to that at Coom Rigg, though no brushwood peat was found overlying the *Phragmites*. Clearly one needs more evidence before concluding anything from the absence of a feature: it may have been overlooked. It is clear however that at least part of Hummell Knowe Moss was at one time a lake, and the Moss as a whole is probably therefore partly of a raised bog nature."

4.5.5 Implications for mire characterisation and typology

Hummell Knowe Moss raises rather acutely some of the issues relating to the characterisation and classification of ombrogenous peatlands.

Ratcliffe (1977) stated that the site, along with four other examples of the 'Irthinghead Mires', was "high quality blanket mire", in its particular case "*Sphagnum*-rich blanket mire", but the reason for his designation of it as 'blanket mire' is neither obvious nor was explained. He did, however, note that "the *Sphagnum* facies [of the vegetation] has close affinities with lowland raised mire vegetation." This has since been confirmed by O'Reilly (2019) in his designation of large areas of the Moss as M18a.

Clymo (1980) introduced Hummell Knowe Moss as "a large blanket mire in the centre of northern England", but subsequently (in the same paper) commented that "The bog as a whole is probably part 'raised' and part 'blanket', as are others in the area." He did not indicate which parts of the Moss he regarded as 'blanket bog', or why.

O'Reilly (2019), who gave some careful consideration to the issues of characterisation of the Border Mires he examined (see Section 4.11), regarded two of his four sub-units at the Hummell Knowe Moss as possible examples of 'spur' mire (a category which he had extended to be a 'mesotope' of 'intermediate mires') and two as possible examples of 'valleyside' mires (which he appears to have regarded as examples of 'blanket bog on shallower peat') (see Table 3). He also suggested the possible affinities of all his sub-sites to 'ridge-raised mires', but it is not clear how he recognised this category, as he probed peat depth only to 1.8 m. There is no evidence from the sub-peat topography (Clymo, 1980) that the eastern unit is significantly 'ridge-raised'; rather it appears to fit rather well within the range of sub-peat topographical variation associated with 'lowland raised bogs' elsewhere. It is possible that the soakway that separates the two shallow ombrogenous domes is associated with a mineral ridge, or that the western unit is more evidently 'ridge raised' than is the eastern unit, but in neither case is this known, on account of the absence of peat profiles. In any case, even if the western dome was found to be associated with a mineral 'ridge', its essential similarity with the eastern dome in surface conditions, vegetation and likely hydrodynamics is such as to suggest it might be perverse to recognise it as a different ecohydrological entity, just on the basis of difference in sub-surface features.

A WETMEC assessment of Hummell Knowe Moss, based on existing WETMEC categories (Wheeler *et al.*, 2009), would be that it consists of a pair of shallow ombrogenous domes (WETMEC 1), separated by a (possibly ombrotrophic) lagg and with both more-or-less surrounded by a mostly narrow, and weakly minerotrophic lagg, in locations where there is some surface run-off from adjoining slopes of mineral ground. It is possible that, towards the south-west corner (where the lagg is generally wider) there is some limited groundwater outflow into the lagg from a band of Tyne Limestone sandstone that forms a flanking knoll (Burn Divot), but this is not certain. Existing relevant WETMEC categories (which were based just on a limited number of lowland ombrogenous peatland sites) do not adequately accommodate variation in ecohydrological types of lagg, such as occurs widely in these upland examples. Nor do they address the conceptual relationships between sloping ombrogenous surfaces (rands) around the margins of ombrogenous domes and the similar sloping surfaces that occur on hillslopes in the uplands, with which they may share many ecohydrological characteristics.

4.6 Long Moss

Long Moss is approximately 52 ha in extent and is situated at NGR: NY 6280 6970, about 600 m to the south-east of the main Spadeadam MoD installation. A small section of the mire comprises unit 7 of Spadeadam Mires SSSI (Figure 6). Prior to forest clearance work between 1998 and 2005, most of Long Moss was covered with planted conifers and intensively drained and furrowed. Restoration works involved forest clearance and blocking ditches, but some narrow belts conifers remain, the mire surface remains extensively furrowed and covered with dense brash, and conifer regeneration is an on-going problem (Eades & Shaw, 2018).

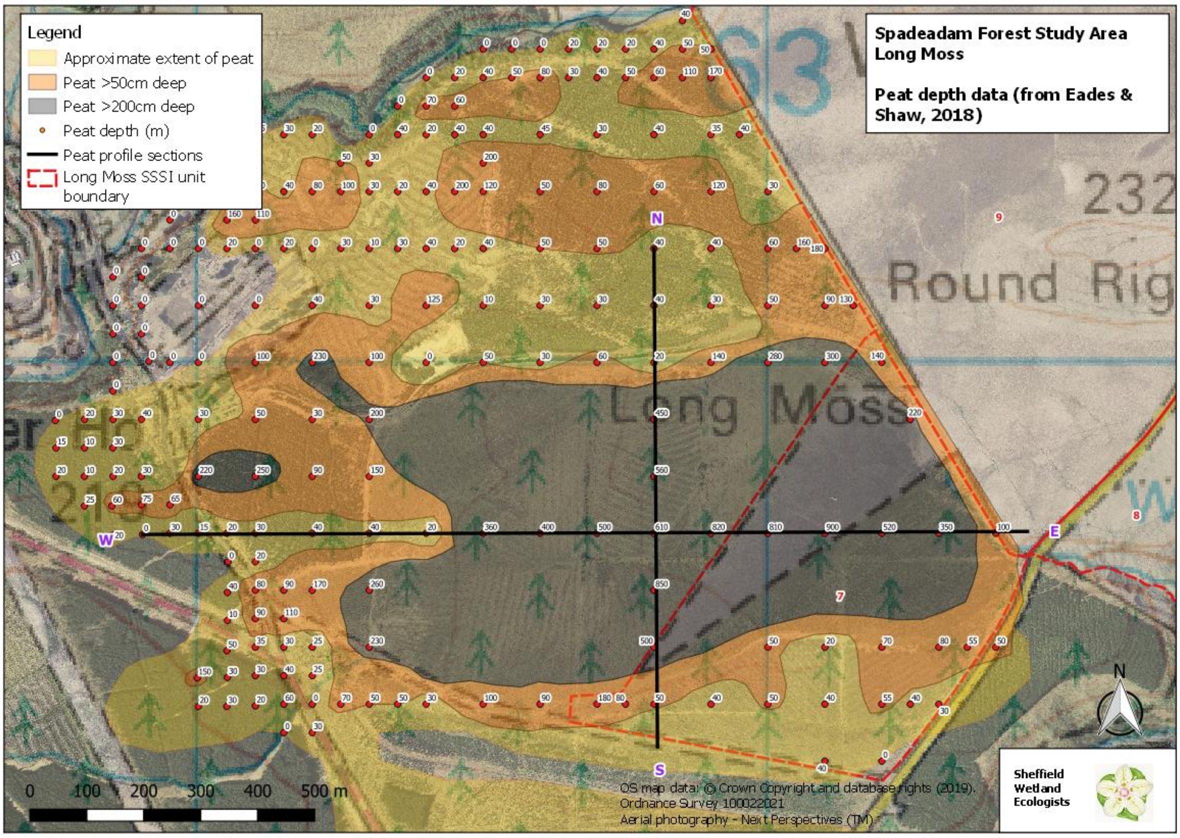


Figure 6. Long Moss peat depths & section locations (from Eades & Shaw, 2018).

4.6.1 Topographical context

Long Moss is a broad, more or less level-surfaced mire at about 220 m aOD that is roughly 1 km long west-to-east and 0.6 km wide north-to-south. Shallow peaty ground slopes gently up to the north before dropping steeply into the valley of the King Water (approximately 200 m aOD). To the west shallow peaty slopes lead down to the Spadeadam MoD road (about 210 m aOD), while a forestry track marks the approximate south-western edge of the deep peat of Long Moss. To the south and south-east shallow peat and peaty mineral ground slopes down toward the Butterburn road and beyond that steeply into the valley of the River Irthing (roughly 170 m aOD). To the east the edge of the mire is marked by Wobiegill Sike, a small tributary of the Irthing. Ditches across Long Moss feed into Wobiegill Sike, as does a larger ditch draining the slopes to the north. Peaty ground continues east of Wobiegill Sike onto the open MoD range of Wiley Sike, towards Round Rigg (232 m aOD).

4.6.2 Geological context

BGS mapping shows that most of Long Moss is underlain by mudstones, siltstones, sandstones and limestones of the Tyne Limestone Formation, with some smaller interleaved bands of Crying Crag Sandstone and Tinklers Crag Sandstone in the north-western corner, and Crammel Linn Sandstone in the south-eastern corner. BGS maps also show Long Moss to be a single body of Peat, whilst a layer of Till is mapped as covering the bedrock surrounding the Peat, and Till is likely to underly the peat deposit itself.

4.6.3 Vegetation

As part of the Cumbria Mire Survey, in 1987 Henry Adams sampled the narrow section of mire that was not afforested at that time, assigning it to **M18a**, and providing two quadrat records[1]. His description is reproduced below. During a further survey by Adams and Jerram (1991), the presence of **M25a** and **M2a** mire types were also noted on the site boundary (see Natural England Science File 2, pages 190–203). They describe the vegetation as follows:

> "Long Moss is a long narrow valleyside flow or possibly ridge-raised mire (?) of small extent and surrounded on both sides by Lodgepole pine plantation (its NE end opens on to *Molinia* mire). Its principal feature is that about 80% of its surface comprises a community that is a good and close-fitting example of *NVC* **M18a** *Sphagnum magellanicum–Andromeda polifolia* sub-community of *Erica tetralix–Sphagnum papillosum* raised and blanket mire. This, together with the corresponding high *Sphagnum* cover (about 85 ± 12%), the wetness and softish consistency of both living surface and peat below, and the scarcity of damage features, indicates that it is an uncut stand of this sub-community important due to its national scarcity. Several ditches do traverse the mire (they were almost brim-full with fast flowing water when seen) but have had no detectable effect on the main general surface.
>
> The main stand as a whole is co-dominated by *Sphagnum magellanicum* and *S. capillifolium*, with abundant *Erica tetralix* and *Eriophorum vaginatum*. Quadrats 1 and 2 are very representative of the less wet and wetter sub-stands respectively of the **M18a**. These exemplify how the high cover of *S. magellanicum* (often around 40% or more) and very low cover of *Calluna* in the wetter areas changes to a reduction of *S. magellanicum* and *E. angustifolium* and an abundance of *Calluna* in the less wet areas. It is interesting how in the undamaged examples of raised-type blanket mire as here, the high cover of *S. magellanicum* is associated with a reduction of *S. papillosum* which occupies a similar niche.
>
> Vertical amplitude is not great (usually little more than about 10 cm or so), the surface undulating only gradually and almost wholly within the T1–(T2) zones. Abrupt-edged hummocks of the type on Butterburn Flow are almost absent and A-zone is scarce. M18b is correspondingly absent and the characteristic hummock top species frequent in this sub-community are only occasional (*e.g. Cladonia impexa*) to very scarce (*e.g. Empetrum nigrum nigrum*) or were not found at all (*e.g. Rhytidiadelphus loreus*). Similarly, the scarcity of A-zone means that *Sphagnum cuspidatum* is rather scarce and no extensive carpets of this species nor natural pools were found [several small carpets (about 1 x 2 to 3m) were seen]. The M18a at Long Moss is in summary a rather wetter and lower amplitude example of the sub-community but nevertheless a close fit.
>
> Another good species-feature of the mire besides the abundance of *S. magellanicum* is the amount of *Andromeda polifolia*, which is frequent almost throughout the M18a."

4.6.4 Peat infill and characteristics

An early peat depth survey by Burlton (2006) was aimed at mapping the extent of peat greater than 2 metres in depth for the Forestry Commission. A 2018 peat depth survey of Long Moss (Eades & Shaw, 2018) closely agreed with the 2-metre peat depth boundary of Burlton, but also showed

[1] Highest MATCH coefficients for HA samples were:277 (NGR: NY 6280 6950): Ma8a, 65.4;
278 (NGR: NY 6295 6963): M18a, 69.4

extensive areas of peat between 0.5 m and 2 m depth, particularly to the west and north (Figure 6). Within the main body of the mire the deepest peat was found towards the eastern end, reaching 9 m in the section that had not been afforested, and it seems likely that deep peat deposits may extend further east into the adjacent land of Wiley Sike, as mapped by the BGS. The mire appears to be more-or-less flat, although a laser-levelling survey would be needed to be certain of this.

4.6.5 Mire ontogenesis

Using the peat depth data of Eades & Shaw (2018), sections along and across the main axis of Long Moss have been sketched (Figure 7). Although levelling of the surface topography was not undertaken, the surface topography of the mire has been estimated based on a combination of mapped OS contours and personal site knowledge.

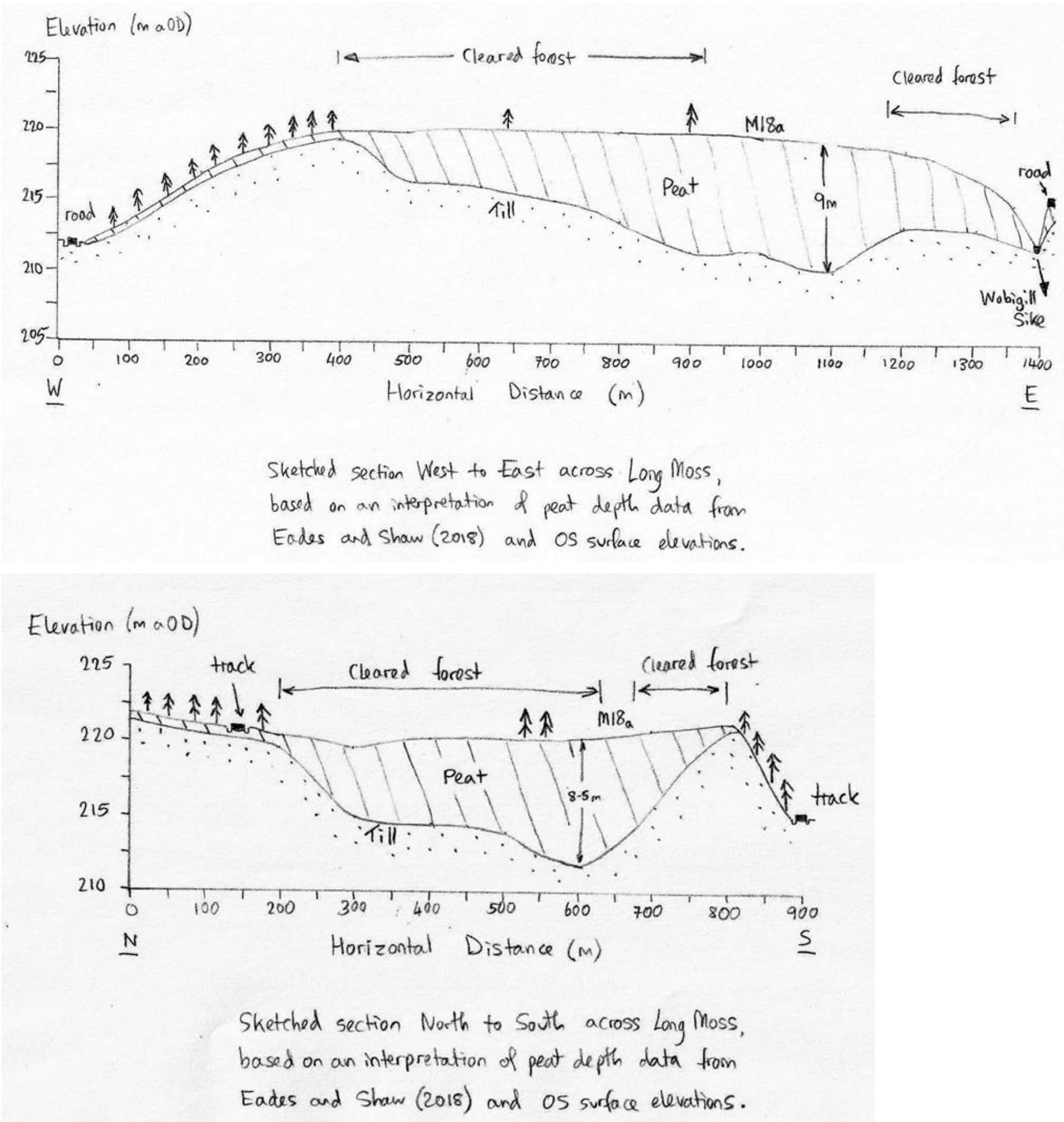


Figure 7. Sections across Long Moss: a) west–east; b) north–south.

Bearing in mind the lack of accurate elevation data, these sections suggest that Long Moss has developed in a broad, shallow depression within gently undulating terrain, constrained by rising ground to the north, and shallow ridges to the west and south. The eastern edge of the bog seems to be marked by the ditched stream that now forms the headwater of Wobiegill Sike, but because the peat depth survey did not extend eastwards of the sike, it is not known whether the peat deposits continue in that direction. Wobiegill Sike may be in part a former lagg stream that has been artificially deepened (though this is not shown on the OS 1868 1st edition map or the 1951 3rd revision map); the depth of Wobiegill Sike just beyond the south-eastern corner of the mire gives it the appearance of a natural watercourse there.

The lack of peat stratigraphic information precludes any knowledge of likely surface conditions at the onset of mire development. The sections suggest the likelihood of paludification, but the possibility of localised terrestrialisation of shallow water bodies in more-or-less closed hollows cannot be discounted.

4.7 Prior Lancy Mire

Prior Lancy is a small mire about 42 ha in extent that forms Unit 1 of the Spadeadam Mires SSSI, which is a component of the Border Mires, Kielder–Butterburn SAC. It is situated at NGR: NY 5989 7165, about 1 km to the north-west of the main MoD site at Spadeadam. The southern third of the mire was afforested but the conifers were felled between 1998 and 2005, although the mire surface remains furrowed. Ditches flank an access track and a simulated airstrip running the length of the mire, though many of these have been blocked since 1998 (Eades *et al.*, 2019).

4.7.1 Topographical context

Prior Lancy is situated in an elongated shallow trough below an MoD installation on the fairly steep slope of Prior Lancy Rigg that forms the northern boundary of the mire, at about 270 m aOD. The southern edge of the mire is marked by the low ridge of Dumblar Rigg (about 262 m aOD) that gradually subsides below the mire to the west. The steep-sided valley of Trout Beck provides the eastern boundary to the site, while a small tributary of the Greensburn flows to the south-west along the western edge of the mire. Prior Lancy mire itself has the appearance of two distinct peat domes (maximum elevation approximately 265 m aOD), the larger to the west, separated by a small ditched stream that receives water from the MoD installation, and then curves to the south-east along the south-eastern edge of the mire, to join Trout Beck. A well-developed lagg area is present along the north-western edge of the mire; it is particularly visible alongside the western part of the bog and flows in a south-westerly direction.

4.7.2 Geological context

BGS mapping shows that Prior Lancy is underlain by sandstone and mudstone of the Fell Sandstone Formation, whilst the land immediately to the north-west comprises interleaved mudstones, siltstones, sandstones and limestones of the Lyne Formation. BGS maps also show Prior Lancy to be a single body of Peat, whilst a layer of Till is mapped as covering the bedrock surrounding the Peat, and Till is likely to underly the peat deposit itself.

4.7.3 Vegetation

Jerram & Adams (1991) surveyed Prior Lancy, and produced a brief description of the vegetation and a simple *NVC* map, which is reproduced in Figure 8. They described two separate peat 'domes': the eastern one had a small central area of M18a *Erica tetralix–Sphagnum papillosum* mire (*Sphagnum magellanicum–Andromeda polifolia* sub-community), with frequent *S. magellanicum*, *Andromeda polifolia* and *Vaccinium oxycoccos* across a surface of hummocks and hollows. This was surrounded by less wet and less diverse M17a *Trichophorum germanicum–Eriophorum vaginatum mire* (*Drosera–Sphagnum* sub-community), which graded abruptly outwards from the domed part of the bog into M25 *Molinia caerulea* mire.

The larger western section of Prior Lancy is separated from the eastern part by a small 'valley' with a ditched stream at its base that flows to the south-east, and that supports a mixture of M25 *Molinia* mire and M23b *Juncus effusus* rush-pasture. The western mire 'dome' was described by Jerram & Adams as being considerably wetter than the east, supporting extensive M18a vegetation with abundant *Sphagnum magellanicum*, *Andromeda polifolia* and *Trichophorum germanicum*, though fewer hummocks and hollows than the eastern 'dome'.

M18 vegetation is considered by many mire surveyors as typically marking out areas of deepest peat, while M17 in contrast is often considered more typical of thinner, better-drained peat.

In addition, there is some base-rich influence from the mineral ground to the north of the bog, possibly partly from the military installation situated on the slopes above the bog. Water from this area appears to have been diverted along the ditched stream between the two bog 'domes' (see below).

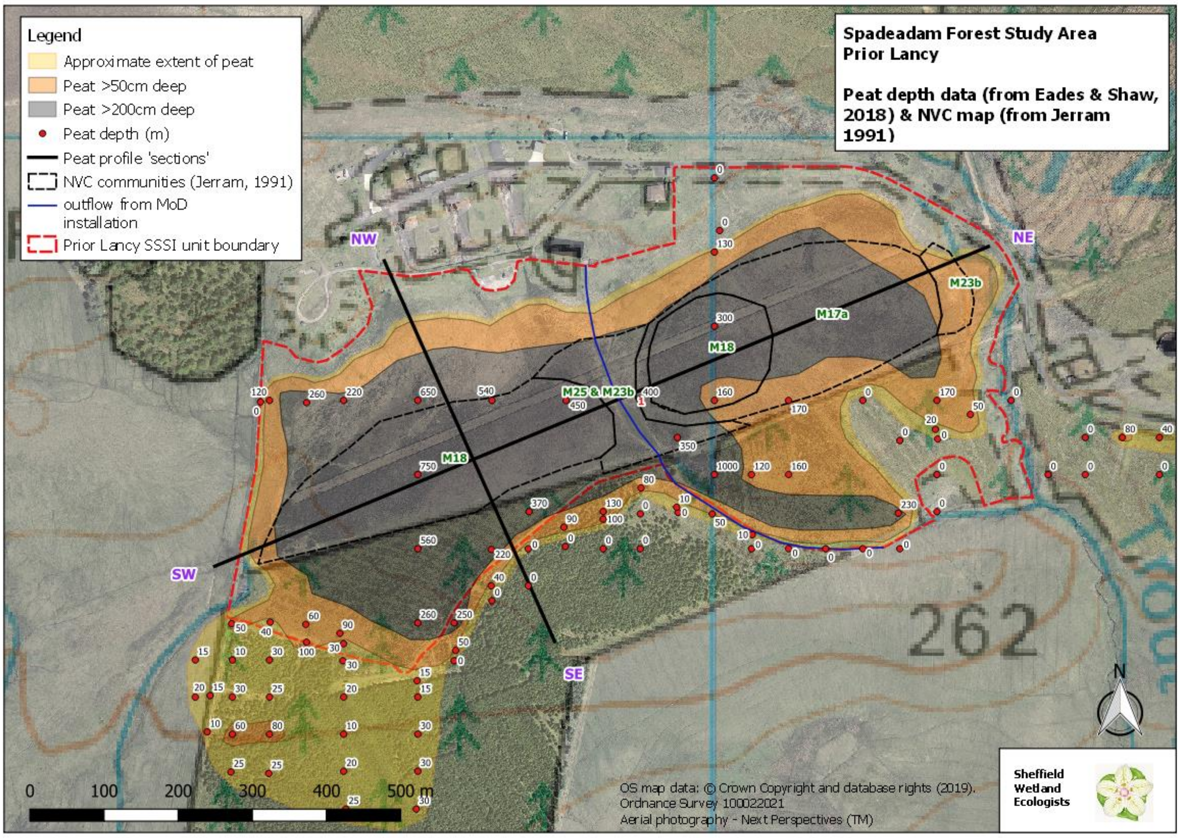


Figure 8. Prior Lancy *NVC*, peat depths and sections.

4.7.4 Peat infill and characteristics

Peat augering was carried out at five points across Prior Lancy during a palaeo-ecology survey by Oxford Archaeology North (2006) although the locations and details of these cores were not provided in their report (as seen by us). OAN recorded peat depths ranging from 2.5 m to 6.5 m and concluded that the mire must have developed in a shallow depression with some deeper pockets. Stratigraphic details from the auger survey showed there to be a base of glacial till, covered by a thin layer of 'organic soil', then fibrous wood peat, followed by *Sphagnum* moss with heather in the upper layers.

A detailed peat depth survey was carried out in 2018 (Eades & Shaw, 2018), though without an investigation of peat stratigraphy. Although the main focus of that work was to identify and characterise the margins of the peat body, peat depths were measured across the two bog 'domes'. A summary of their description is given below, and locations and depths of peat cores are shown in Figure 8:

> "The peat body is roughly 1 km long and about 0.5 km across at its widest, and the axis of the bog lies south-west to north-east. The peatland extent closely matches the SSSI unit boundary, although shallow peat extends beyond the unit to the south-west. The most extensive area of deep peat is in the western part of the site, reaching about 7.5 m. However, there is a narrow spur of deep peat following the outflow channel in the south-eastern part of the site, and there in one place peat and underlying soft sediments were at least 10 m deep."

4.7.5 Mire ontogenesis

Because of the design constraints of the peat depth project (Eades & Shaw, 2018), probing points were restricted to a north–south, east–west grid, and levelling of the surface topography was not undertaken. Consequently, a true section along and across the main axis of the site cannot be made using these data. Instead, 'virtual' sections have been sketched, based on the peat depth data and a working knowledge of the surface topography of the mire (Figure 9).

Bearing in mind the limitations of the peat depth dataset and the lack of accurate surface levels, the sections appear to show that Prior Lancy has developed in a trough between two ridges, the floor of which slopes generally to the south-west but for at least part of its length forms a shallow depression. This conclusion is supported by the results of OAN's peat stratigraphy survey, which suggested that mire development was initiated by paludification ('wetting up') of woodland, rather than terrestrialisation of a water-filled basin.

The peat deposit has developed into a shallow dome that is most evident along its longer, NE–SW axis, and because the peat depth shallows quite rapidly beneath the eastern 'dome', it seems a distinct possibility that the double-domed appearance may be the artificial result of a drainage channel cut across the bog to take cooling water effluent from the adjacent (now disused) missile research installation. This hypothesis is supported by historic OS maps, which do not mark a watercourse crossing the mire in either the 1868 1st edition, the 1901 1st revision, or the 1951 3rd revision, though they do show the Trout Beck to the east, the tributary of the Greensburn to the west, and the south-eastern tributary of the Trout Beck, into which the MoD outflow stream now flows.

The relatively steep slope at the south-western end could be considered a form of rand dropping down to a lagg stream that forms a tributary of the Greensburn.

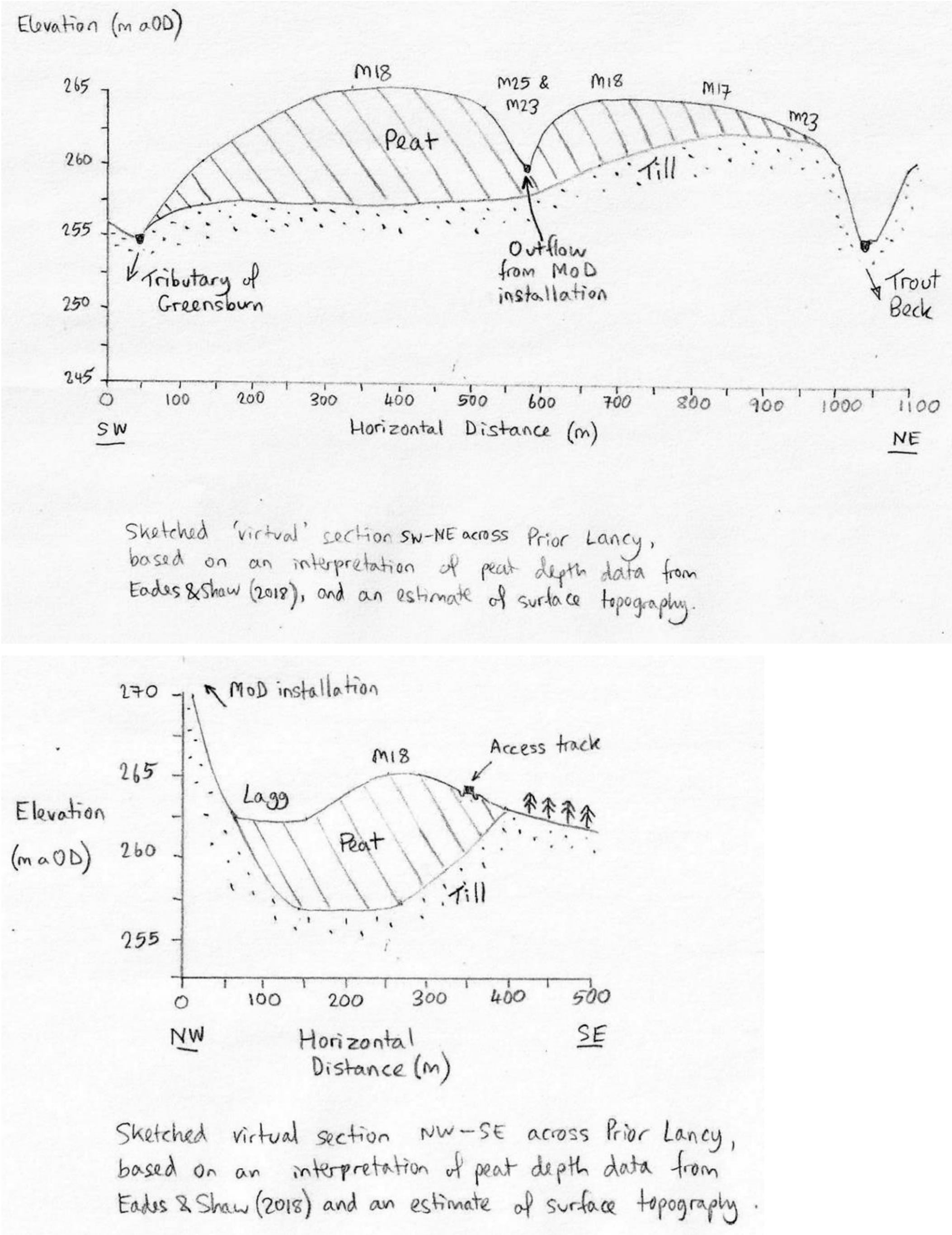


Figure 9. Sections across Prior Lancy: a) SW–NE; b) NW–SE.

4.8 Sheep Rigg Moss

Sheep Rigg Moss is situated at approximately NGR: NY 6370 7040, about 2 km due east of the MoD base at Spadeadam, and covers about 40 ha, forming part of unit 9 of the Spadeadam Mires SSSI. This area has never been afforested and is used as part of the military training area. Adams (Jerram & Adams, 1991) described Sheep Rigg Moss as "a very large… 'high quality' valleyside flow (a type of blanket mire in the broad sense)".

4.8.1 Topographical context

Sheep Rigg Moss is about 1 km long south-west to north-east and 0.4 km wide north-west to south-east, and is situated on a very gentle slope from the mineral ridge marked by Round Rigg

(232 m aOD) and Sheep Rigg, north-westwards down into the valley of the King Water (approximately 215 m aOD). South of Round Rigg and Sheep Rigg lies the Butterburn road, and to the south-west is the afforested land above Long Moss. The north-eastern edge appears to be marked by a drain that feeds into Stour Sike, a tributary of the River Irthing. The mire itself is constricted about halfway along its length: the eastern part is almost flat, whilst the western part has a slight slope to the west and north-west.

4.8.2 Geological context

BGS mapping shows that most of Sheep Rigg Moss is underlain by limestones, mudstones, sandstones and siltstones of the Tyne Limestone Formation, with some smaller interleaved bands of Crammel Linn Sandstone, Green Grove Sandstone and Collering Sandstone in the east, and Crying Crag Sandstone beneath the King Water in the north-west. BGS mapped Peat covers most of this SSSI unit, with the exception of the Till-covered hillocks of Round Rigg and Sheep Rigg, and the valley of the King Water. The base of the valley is mapped as Alluvium, with Till along its lower slopes, and Till is likely to underly much, if not all, of the Peat.

4.8.3 Vegetation

Henry Adams described Sheep Rigg Moss in some detail as part of the Cumbrian Mire Survey (English Nature, 1994) and later survey work (Jerram & Adams, 1991). An abridged version is reproduced below.

> "The Moss has a near to 100% *Sphagnum* cover on a wet and soft uncut peat surface. The bulk of the mire surface is [the] M18a community, with abundant small patches of *Sphagnum cuspidatum* (=M2a/c.M2a) within it, and with its … margins… clearly demarcated by the abrupt appearance of *Molinia caerulea*, and a consequent changeover to the M25a [community] that surrounds most of the Spadeadam mires in the Wiley Sike area.
>
> The Eastern half of Sheep Rigg Moss is… of particular interest for its … great abundance and very frequent dominance of *Sphagnum magellanicum*. Its surface is very soft, spongey and wet, and its microtopography has a very low vertical amplitude (mostly flat *Sphagnum* lawn near the TI/A1 boundary; carpets small and very shallow though Frequent/Abundant; hummocks and tussocks only occasional). The Western half …, though wet and fairly soft, is not as soft as in the Eastern half, and much more contrastingly, has a high vertical amplitude, being hummocky and tussocky. The herb-layer cover is low in the Eastern half, high in the Western half; and the *Sphagnum* cover though very high (99 to 100%) in the Eastern half, is reduced (though still high) in the Western half by the density of the tussocks. The noticeably tussocky growth of *Eriophorum vaginatum* and *Trichophorum cespitosum* in the Western half (where Ev and Tc, and to a lesser extent Et, share dominance of the herb layer) does not occur in the Eastern half (though Ev & Tc [are] still F/A). Over both halves *Andromeda polifolia* (the most exclusive M18a indicator species) is extensively constant."
>
> **Margin transitions in the M18a**
>
> In common with several of the other M18a mires in the Wiley Sike area there is a gradual transition in the appearance of the M18a towards … the surrounding M25a, in association with an increase in the firmness of the peat surface... This is due primarily to an increase in *Trichophorum* cover... Other general changes include an increase in the herb-layer cover and a decrease in *S. magellanicum* cover. However as the species present remain essentially the same as for the central M18a, it is better to classify these margin transitions as a "margin transition variant" of M18a rather than as a separate sub-community such as M17a blanket mire.
>
> **The M25a**
>
> The abrupt change in the *Molinia* from total absence in the M18a to dominance in the adjacent M25a is a typical feature in the mires of the Wiley Sike area, and although sometimes associated with the drying effect of a ditch, it mostly appears to be a natural change and thus of interest in being so abrupt, and in that … M18a stands on raised mires so often instead have an edge determined by man's activities (*e.g.* ditching or cutting). Water-retentiveness/aeration of the peat surface is undoubtedly an important

factor, but the abruptness suggests that here the *Molinia*-presence in itself probably improves conditions for itself to reach dominance (a sort of positive feedback). The M25a around Sheep Rigg Moss (and around the Spadeadam mires in general) is variable both floristically and in 'interest' factors such as species richness, and ranges from 'poor fen' variants (with *e.g.* abundant M6i species such as *Sphagnum recurvum* and *Polytrichum commune*) to 'erico-sphagnion'-type variants with some of the species of the M18a remaining prominent. The M25a should therefore not be dismissed as being of low interest before examination, and particularly as it forms the natural/semi-natural Moss surrounds.

The highest MATCH coefficients[1] for the three 1989 Adams' samples that are available are:

Sample	Code	Coefficient	*Trichophorum germanicum* cover (Domin)	Easting	Northing
281	M18a	72.2	2	364200	470600
282	M18a	65.7	3	364000	470600
283	M18a	68.1	4	364100	470600

4.8.4 Peat infill and characteristics

Peat coring at 'Wiley Sike Moss' (aka Sheep Rigg Moss) was carried out by Oxford Archaeology North (OAN, 2006) using a gouge auger at a series of 17 locations on the eastern part of the Moss, following intersecting south–north and an east–west transects.

Peat depth was more than 8.5 m at core 6 (NGR 364288 570649), which was 200 m from the Butterburn road. From there coring demonstrated peat depths of between 8.50–7.50 m north across the mire for 150 m before rapidly shallowing. Moving west from the centrally placed core 6, peat depths declined slowly towards NGR 363643 570559.

4.8.5 Mire ontogenesis

OAN (2006) considered that the Moss probably developed as a raised mire in a steep-sided east–west oriented valley that has now completely infilled with peat. The peat stratigraphy suggests that the mire developed from open, wet woodland originally occupying the valley floor, being replaced by acidic fen with occasional reeds and scrub, and finally *Sphagnum* bog with cottongrass and heather. Radiocarbon dating of peat near to the base of the bog provided an age of about 7000 years before present, suggesting that the mire began to form in the early- to mid-Holocene (post Glacial) period (Oxford Archaeology North, 2006).

4.9 Standing Stone Moss

Standing Stone Moss is situated at approximately NGR: NY 6414 7202, about 3 km north-east of the MoD base at Spadeadam, and covers about 10 ha, forming one of several mires in unit 5 of Spadeadam Mires SSSI. This area has never been afforested and is used as part of the military training area. Jerram & Adams (1991) described this area as an "extensive valley-side flow", though not as high quality as Sheep Rigg Moss.

[1] MATCH coefficients provide an estimate of 'goodness-of-fit' of the sampled vegetation to the published *NVC* community and sub-community types. The higher the coefficient, the better the 'fit'.

4.9.1 Topographical context

Standing Stone Moss is situated on a broad 'shelf' at about 270 m aOD, immediately north-west of Standing Stone Rigg, and near the top of a south-west–north-east trending ridge, whose south-western end is marked by Watch Rigg (284 m aOD). Northwards this leads to the extensive mires of Berry Hill. The headwater of Crowrigg Sike bisects the Moss, dropping away steeply to the south, then south-east to join the Rairing Sike. To the south-west the ground slopes more gently down to the King Water at about 230 m aOD.

4.9.2 Geological context

BGS mapping shows most of this area to be underlain by mudstones, siltstones, sandstones and limestones of the Tyne Limestone Formation, and Tinklers Crag Sandstone. BGS mapping shows most of the bedrock to be covered by either Peat or Till, and Till is likely to underly the peat deposits.

4.9.3 Vegetation

Jerram & Adams (1991) described the vegetation of this area; their vegetation descriptions are reproduced below:

> "Between Watch Rigg and Standing Stone Rigg (NY 635722–NY 649719), M25 *Molinia* mire and grassland predominates, however there are small areas of blanket mire dominated by *Trichophorum germanicum* and tussocks of *Eriophorum vaginatum* (M17a *Scirpus cespitosus–Eriophorum vaginatum mire, Drosera–Sphagnum* sub-community). These mires tend to have a wet surface with occasional small *Sphagnum* hummocks. Overall *Sphagna* tend to be occasional to frequent but towards the centre the surface tends to become wetter and *Sphagnum magellanicum* contributes significantly to the ground cover and this area is likely to be M18a *Erica tetralix–Sphagnum papillosum mire (Sphagnum magellanicum–Andromeda polifolia* sub-community). The transition between the two communities is very gradual.
>
> Similar areas of blanket mire are found south of Tip Hill and on the eastern side of Standing Stone Rigg. The mire below Standing Stone Rigg is similar to the above, however it has a series of parallel drains running across it, each of which have a narrow margin of *Molinia* mire.
>
> To the west of Berry Rigg and adjacent to the plantation is an area of degraded blanket mire. *Molinia, Scirpus cespitosus* and *Sphagna* are abundant and typical blanket mire species such as *Drosera, Andromeda, Vaccinium oxycoccos* and *Sphagnum magellanicum* are present though tend to be rare. This mire is 'transitional' between M25 and M17. It is frequently crossed by motorbikes and the wettest area is badly rutted and eroded."

4.9.4 Peat infill and characteristics

Peat coring at Standing Stone Moss was carried out by Oxford Archaeology North (OAN, 2006) using a gouge auger at four locations east–west between NGR 364398 572000 and 364267 572009, and a further two locations south from the deepest core of the east–west transect. Peat depths ranged from 2.5 m to 3.5 m.

4.9.5 Mire ontogenesis

OAN (2006) considered that the mire at Standing Stone Moss developed in a shallow depression then spread more widely and based on this they classed it as a blanket mire. Macrofossil analysis found a basal deposit of amorphous peat with wood fragments, *Juncus* and *Vaccinium oxycoccos* seeds, suggesting that the mire was initiated by paludification (wetting-up) of open woodland. This was overlaid by monocot peat with some wood and bryophyte remains, with increasing cottongrass and *Sphagnum* content closer to the surface. OAN considered that 'blanket mire' had formed the uppermost 1 m of peat. Charcoal fragments were present throughout the sequence and could be signs of anthropogenic burning.

Radiocarbon dating of the basal peat indicated that peat formation began around 5200 years before present, in the Late Mesolithic / Early Neolithic period (OAN, 2006).

4.10 The Wou

The Wou forms part of Thirwall Common, covers about 303 ha, and is located at approximately NGR: NY 676 702, roughly 500 m SE of Wileysike House and the River Irthing. It comprises units 28–32 of the Kielder Mires SSSI and is a component of the Border Mires, Kielder–Butterburn SAC. About 60% of the site is open mire on flat or gently sloping ground, the remainder is a steeper afforested slope. Part of the afforested ground was cleared as part of an EU LIFE-funded rehabilitation project that ran from 1998 to 2003 (Northumberland Wildlife Trust, 2003). The open ground consists of a series of separate peat domes with sloping rands and lagg fen areas between them, bordering and grading into a long valley mire with minerotrophic fen. Hendon, Charman & Kent (2001 p.144) considered this site to be "an oligotrophic valley mire" or a "mesotrophic valley mire".

4.10.1 Topographical context

The Wou is situated in a broad, shallow ENE–WSW trending valley, which forms the head of the Crammel Burn, a tributary of the River Irthing. At its north-eastern end the head of the valley lies at about 230 m aOD, below (north-west of) the small peak of Burn Divot (258 m aOD). The lowest point of the valley, at its western end, is at about 205 m aOD. To the south and south-east, gentle slopes rise up to a ridge marked by Watch Hill (242 m aOD) and Black Rigg (243 m aOD), before falling more steeply south-eastwards into the valley of the Tipalt Burn. The northern side of The Wou is marked by an afforested ridge that reaches an altitude of about 225 m aOD at Peat Rigg and White Rigg, before dropping north-westwards to the River Irthing.

4.10.2 Geological context

BGS mapping shows the entire area to be underlain by mudstones, siltstones, sandstones and limestones of the Tyne Limestone Formation, and most of the bedrock to be covered by Peat, with Till on the higher ground to the north and south; Till is likely to underly the peat deposits.

4.10.3 Vegetation

As part of his survey of The Wou, O'Reilly (2019) divided the site into 12 sub-sites (Figure 10), 11 of which were areas of bog habitat, the twelfth being fen habitat (sub-site TW-A). Within these he recognised several *NVC* types (Table 2) but did not present a vegetation map in his draft report.

Marked transitions between plant communities were also often observed: in some areas the drier bog vegetation of the rand was classified as M18 but reportedly appeared different to the type of M18a in the centre of the bog. For example, at sub-site TW-H the M18a of the rand had *Eriophorum vaginatum* and *Molinia caerulea*, but less *Erica tetralix*, *Trichophorum germanicum* and *Sphagnum magellanicum* compared to the M18a of the bog centre. In the outer edges of the rand at TW-H the vegetation changed to M20-w, followed by a narrow lagg zone of M2b.

In addition to the eleven ombrotrophic mire sub-sites, The Wou also supports a long minerotrophic mire (sub-site TW-A), described by O'Reilly as a two-kilometre long valley mire with large stands of M2, M6a/b and M4 vegetation, which include some large populations of the uncommon sedges *Carex limosa* and *Carex magellanica.*

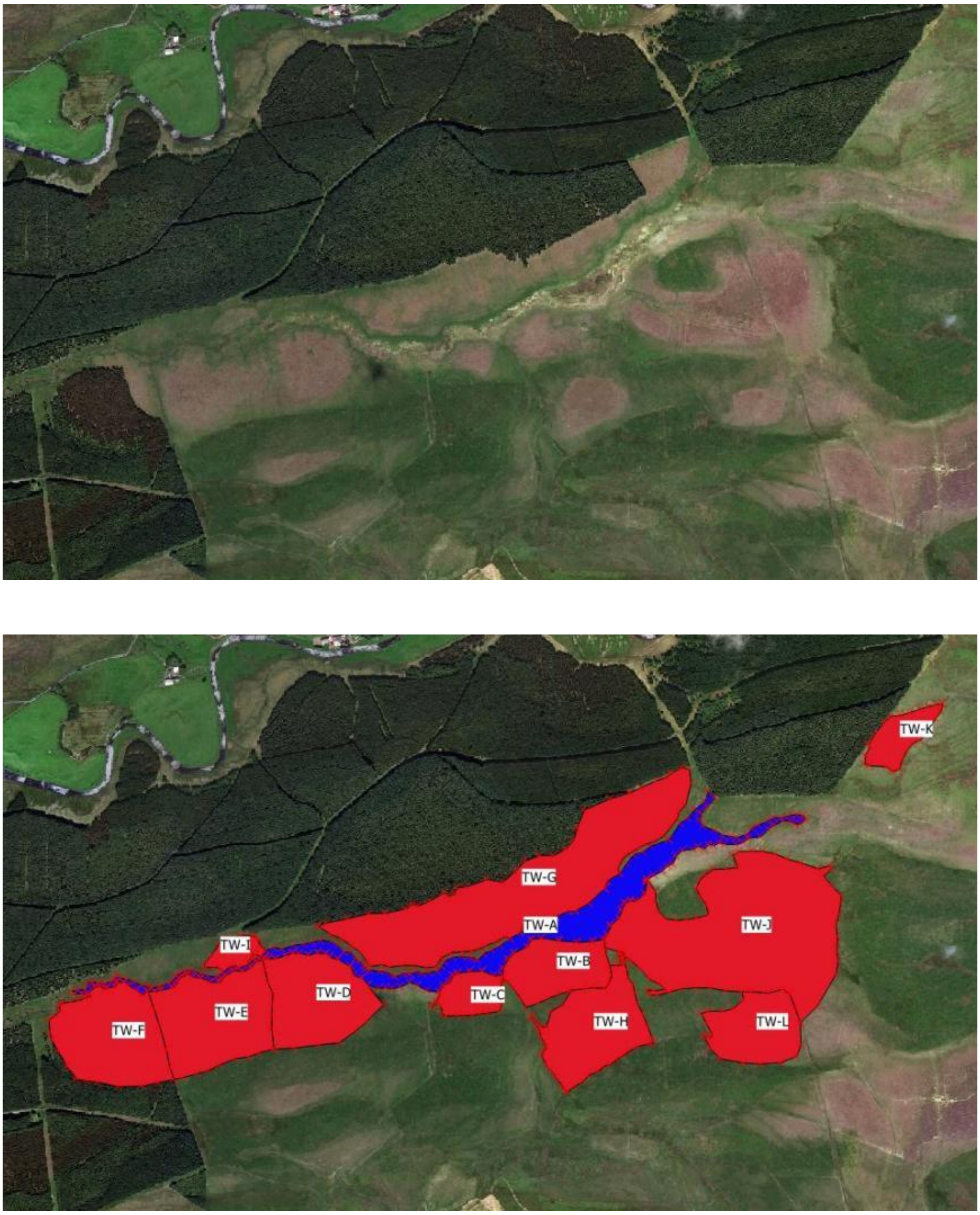


Figure 10. The Wou sub-sites (reproduced from O'Reilly, 2019).

(Red fill denotes bog sub-units, blue fill denotes fen sub-unit)

Table 2. *NVC* vegetation types at The Wou (from O'Reilly, 2019).

(note that hyphenated variants are those proposed by O'Reilly (2019).

***NVC* code**	**Community or sub-community name**
M2b	*Sphagnum cuspidatum/recurvum* bog pool community, *Sphagnum recurvum* sub-community
M4	*Carex rostrata–Sphagnum recurvum* mire
M6a/b	*Carex echinata–Sphagnum recurvum/auriculatum* mire, *Carex echinata* / *Carex nigra–Nardus stricta* sub-communities
M6ai	*Carex echinata* sub-community, *Sphagnum recurvum* variant
M6ci	*Juncus effusus* sub-community; *Sphagnum recurvum* variant
M6di	*Juncus acutiflorus* sub-community; *Sphagnum recurvum* variant
M18a	*Erica tetralix–Sphagnum papillosum* raised and blanket mire, *Sphagnum magellanicum-Andromeda polifolia* sub-community
M19a	M19a *Calluna vulgaris–Eriophorum vaginatum* blanket mire, *Erica tetralix* sub-community
M19-f	*Sphagnum fallax (recurvum)* variant
M20-w	*Eriophorum vaginatum* blanket and raised mire, wet variant
M20-d	*Eriophorum vaginatum* blanket and raised mire, dry variant
M23	*Juncus effusus/acutiflorus–Galium palustre* rush-pasture
M23a	*Juncus acutiflorus* sub-community
M23b	*Juncus effusus* sub-community
M25a	*Molinia caerulea–Potentilla erecta* mire, *Erica tetralix* sub-community
S4	*Phragmites australis* swamp and reed-beds

4.10.4 Peat infill and mire ontogenesis

During O'Reilly's vegetation survey at The Wou, peat depths were apparently measured at each quadrat sample to a maximum of 1.8 m depth. These data were not reported, and may anyway have been of limited consequence, as in the central part of the mire peat depth varies between about 1–6 m (Hendon *et al.*, 2001). The sub-peat topography of the mire, based on depth profiles reported by these authors, was irregular, with ridges and hollows (possibly troughs or basins). Greatest peat depth was recorded in some of the hollows and shallowest across a particularly upstanding ridge. However, only a small part of the mire was crossed by these sections and the wider sub-surface topography does not seem to be known, nor has peat stratigraphy been reported. Peat deposits are present throughout the plantation to the north of the SSSI, almost to the top of the ridge (I. Diack, pers. comm. 2020).

The reported presence of rand and lagg zones around many of the sub-sites of The Wou imply that the central bog areas often had a domed profile, but this is not made explicit by O'Reilly. There is possible evidence of doming in one of the sections from the central part of the mire provided by Hendon *et al.* (2001), but more detailed investigations of peat depths and stratigraphy are needed to clarify such matters.

4.11 Implications for mire characterisation and typology

As part of his vegetation survey of six Border Mires, O'Reilly (2019) discussed the issue of whether to describe a bog as 'raised bog', 'blanket bog', or 'intermediate bog'. He considered that many of the Border Mires with deep peat are difficult to classify because the standard view of a raised bog is that of a large dome that has developed in a lowland setting, usually in a floodplain or coastal plain situation. However, the Border Mires are in a semi-upland landscape, are often relatively small, and usually occur within a more extensive area of shallower peat on sloping ground. O'Reilly contemplated the use of the terms 'intermediate bog', 'ridge-raised bog', and 'semi-confined raised bog', considering that ecologically they share more characteristics with lowland raised bog than with 'typical' blanket bog. He concluded that most of the Border Mires on deep ombrotrophic peat should be described as 'raised bog'.

Also as part of his Border Mires survey, O'Reilly (2019) devised a tentative classification of the bog types encountered in that area, based on a modification of Lindsay's (1995) blanket bog classification, and reproduced in Table 3. It should be noted that for the purpose of his survey O'Reilly defined 'deep' peat as greater than 1.8 m depth but did not clearly define 'shallow' peat depths.

Table 3. Border Mires bog 'mesotopes', from O'Reilly (2019).

Bog type	Description
Unconfined raised	Discrete dome-shaped deep peat bodies surrounded by an extensive area of shallower blanket bog. Unlike the spur and watershed categories below, there is relatively little obvious change in underlying topography or slope from the bog centre to the surrounding land.
Ridge-raised	Two or more dome-shaped areas of deep peat, which have fused across an intervening underlying ridge, covered in shallower peat.
Intermediate spur	Discrete, deep peat bodies on a spur (i.e. the surrounding land is higher on one side and lower on the other three sides), with shallower blanket peat on the margins.
Intermediate watershed	As 'Intermediate spur', but the surrounding land is lower on all sides.
Blanket valleyside	With shallow peat on gently sloping ground, without abrupt changes in topography. These bogs were relatively homogeneous, without sharp contrasts between areas on deep or shallower peat.

O'Reilly considered that The Wou supported examples of all the above bog types except 'Intermediate watershed'. He also observed that different parts of a single site appeared to be referable to different categories. However, regarding his categorisation of 'Ridge-raised' types, there is no reason to suppose that the peat either side of the ridge was necessarily domed, nor that once-separate domes have necessarily 'fused'. Nor is it known how, with a stated peat coring depth of 1.8 m, he assessed the sub-peat topography. Whilst his approach is interesting as an attempt to utilise the 1995 blanket bog classification, it also helps to demonstrate how difficult it can be to effectively assign real bog sites using that system.

These considerations suggest that there are two particular difficulties associated with the use of existing bog categories to accommodate the sites considered in the Border Mires. One is that the categories are themselves based on locational and ill-determined criteria; the other is that there has generally been a desire to regard entire sites as belonging exclusively to a single category. However, as O'Reilly has recognised, the sites in question are themselves variable in their characteristics, both between and within sites, and are not easily 'shoe-horned' into existing categories, even when these are loosely defined. The category of 'Intermediate Bog', which might be considered by some to be appropriate for many of the Border Mires, does not seem to assist in this process, because it represents just a further ill-defined entity interpolated amongst others. Moreover, 'intermediate mires' can be 'intermediate' in different ways and in different parts of a single site, so use of this category provides little insight into any distinctive ecohydrological features of those mires that have been included within its compass. Hence, the practical use of this concept and term seems to have been mainly as a convenient label for sites that are not obviously 'normal blanket bog' but which are thought to be in the 'wrong place' to be considered to be 'raised bog'. This points to a real need for the characterisation and categorisation of mires to be more flexible and to be based more upon the actual characteristics of sites in the field than is the case with the existing categories of ombrogenous examples.

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5 Silver Flowe, Galloway

5.1 Background

The Silver Flowe is a long, narrow peatland complex that occupies some 4.2 km of the length of the floor of the glaciated valley of the southward-draining Cooran Lane[1]. This valley is part of a longer, narrow, north–south valley between the Merrick Hills on the west and the Rhinns of Kells to the east which drains both south (Cooran Lane) and north (Gala Lane). On either side of the Silver Flowe, the valleysides rise steeply, steepest on the west side to Craignaw (645 m aOD) and its associated ridge, somewhat less steep on the east to Tops of Craigeazle (487 m aOD) and then to the ridge of the Rhinns of Kells, which reaches to over 800 m aOD.

The Silver Flowe and its surroundings are included on the British Geological Survey Scotland map 8E, which is supported by a fairly recent *Memoir* (Floyd, 1999). All of the Silver Flowe, and much of its catchment, are located within the Loch Doon pluton, a large igneous intrusion into the Ordovician sediments of the Southern Uplands Terrane. The Cooran Lane valley and the slopes to the west occupy the granite core of the pluton. Eastwards, on the higher slopes this grades into granodiorite and then into modified wackes of the Ordovician Portpatrick Formation at the Rhinns of Kells.

The high ground of the area appears to have formed a centre of ice flow during the Devensian glaciation, with radial ice flow from the Merrick and Rhinns of Kells ridges, and from Mullwhachar (692 m aOD), including ice flow south along the Cooran Lane valley. Granite and granodiorite is exposed over significant areas, particularly on the upper and steeper valley sides, but 'hummocky glacial deposits' (morainic material) are mapped along some of the lower slopes (and elsewhere) and are thought to underlie the peat deposits in the valley bottom (Floyd, 1999), though no details are given. In places there are apparent lateral moraines flanking the mires.

As mapped by BGS, peat occupies almost all of the bottom and some the lowest slopes of the Cooran Lane valley, though replaced by Alluvium immediately alongside the river.

Ratcliffe & Walker (1958) considered that "the bogs of the Silver Flowe receive about 90 in. (225 cm) of rain each year", based on data from Loch Dee. Boatman (1983) provided an annual mean of 1883 mm from Clatteringshaws Loch, about 9 km south-east of the Flowe, for 1964–79, and considered that a water deficit was rare in any month.

5.2 The Silver Flowe Peatlands

A brief description of the peatlands of both the Gala Lane and Cooran Lane valleys was made by Lewis (1905), under the heading "The Upland Mosses of the Merrick and Kells District". He commented that "the 5 miles of peat south of a line drawn from the foot of Craignaw to Elderholm is covered at present by *Sphagnum*" whilst the 5 miles of peat to the north "is better drained and tenanted by a much drier type of vegetation consisting of *Calluna vulgaris*, *Eriophorum vaginatum, Myrica gale,* Carices and *Juncus squarrosus.*"

Since then, various ecologists have examined the site. Ratcliffe & Walker (1958) made an initial, but quite detailed, ecological study and Birks (1972) made palynological investigations in a couple of locations, but much subsequent ecological work was associated with the

[1] Water course joining the Dungeon Lochs to Loch Dee.

University of Hull, and the findings of various publications have been synthesised compendiously by Boatman (1983).

Although peat occupies the bottom of much of the Cooran Lane valley, ecologists have focussed their attentions on areas of 'patterned mire' (areas with pools and hummocks and lawns of *Sphagnum*) and little is known about the peat infill outwith these. Ratcliffe & Walker (1958) stated that there were seven main patterned bogs (though they mapped eight), which formed a chain along the valley; they helpfully named them after nearby features. The most southerly example, Craigeazle Bog, is the only example east of Cooran Lane. Northwards, there are bogs west of the river, in up-valley sequence: Snibe, High Cornarroch and Craignaw Bogs. The main river bends north-eastwards at Craignaw Bog, and Brishie Bog is on the north-west side of it, but also at the south-eastern (lower) end of a broad south-east trending interfluve which separate two of the main tributaries (Brishie Burn and Saugh Burn) of Cooran Lane. Further north-west and higher on this interfluve, on flattish ground east of Long Loch and Round Loch, three main patterned areas were identified, two of them named the Long Loch Bogs, the other (the most northern), Round Loch Bog.

Ratcliffe & Walker (1958) (also Ratcliffe, 1964) considered that the seven bogs were all very similar in their vegetation, but formed a graded series topographically. They considered that the most southern (Craigeazle Bog) had "the appearance of a typical raised bog" but those at the northern end "must be classed as blanket bog. In topography they have little in common with the bogs at the other end of the valley, for laggs, rand and convex shape are all missing, but the pool and hummock complex of all three clearly links them with the rest of the Silver Flowe". As both bedrock and climate along the length of the mire are likely to be the same or very similar, this sequence of sites provides an opportunity to assess possible causes of 'raised-boggyness' *versus* 'blanket-boggyness'.

5.3 Vegetation

Ratcliffe & Walker (1958) used a number of informal vegetation categories to give some account of the vegetation of the Silver Flowe. These were subsequently considered and partly adopted by Boatman (1983).

5.3.1 Patterned surfaces

These have provided the focus of much of the ecological investigation on the Silver Flowe and were referred to by Ratcliffe & Walker as a "pool and hummock complex". Within this they distinguished various microtopographical elements, in drier areas, they recognised wet and drier "*Sphagnum* flat" and medium and tall hummock components; and in wetter areas there were shallow pools (often gradationally vegetated with *Sphagnum*) and deep, mostly steep sided, pools, usually with little or no *Sphagnum* but often with *Menyanthes trifoliata.* Boatman (1983) pointed out that there were also "hollows", most often inundated but 'dry' during some summer periods. Both pools and hollows can be aligned as a finely branched network or, particularly on the slopes, elongated across the gradient of the slope. Boatman reported that "most of the stands assigned to the Trichophoreto-Eriophoretum [of McVean & Ratcliffe (1962)] are located in areas exhibiting a patterned surface", though the microtopographical variation gave rise to consider local variation in species composition. Most examples of this community occupied slopes of less than 1°. There is a rather confused relationship between slope and patterning. Boatman (1983) reported that "The fringes of most of the patterned mires, where gradients are somewhat higher than in the centre, generally consist of hummock–hollow pattern. It seems that pools reach the edge of a patterned area only where there is a considerable increase of surface gradient over a short distance. However, areas of hummock–hollow pattern are not necessarily associated with gradients steeper than those occupied by ridges and pools. The gradient across the western lobe of Brishie mire, with hummock–hollow pattern, for example, is as low as that across the eastern lobe with pools and flays, and considerably less than the steepest gradient across the eastern group of pools on Long Loch B mire."

5.3.2 'Intermediate bog'

The 'intermediate bog' of Ratcliffe & Walker (1958) should not be confused with the 'intermediate bog' of Ratcliffe (1964); the first refers to a vegetation category, the second to a type of mire (as far as the current authors can determine). According to Ratcliffe & Walker 'intermediate bog' is "a type of vegetation transitional in character – and sometimes in situation – between the pool–hummock complex on the one hand and the valley Molinietum and hillside blanket bog on the other". They did map the distribution of this vegetation but noted that "Intermediate bog covers some areas adjacent to the pool–hummock patches of the Silver Flowe and is extensive on the gently inclined tongue between the Long Loch and Brishie Bogs". They regarded 'intermediate bog' as representing the drier components of their 'pool–hummock complex': "intermediate bog has almost exactly the same composition as 'medium hummock' of the pool–hummock complex and represents an extensive development of this micro-community". However, all of the samples recorded by Boatman from the area between Long Loch and Brishie Bogs were referred by him to the Molinieto-Callunetum not to the Trichophoreto-Eriophoretum, whereas the latter community appeared to occupy some surfaces around the patterned mire area on Craigeazle Mire, and that all species characteristic of this community occurred across the full width of the rand at this site[1]. Boatman (1983) commented that that stands on the area between Long Loch and Brishie Bog (apparently referring to the Molinieto-Callunetum) on slope of about 2° and others on somewhat steeper slopes (up to 10°), with no "consistent differences in vegetation that can be related to gradient".

5.3.3 Rand

Ratcliffe and Walker (1958) mapped the rand around the mire units at the Silver Flowe and stated that "This term applies to the relatively steep-sided and better-drained bog margin carrying a vegetation different from that of the central area. Its width varies but an average figure is about 100 m. In many places there is a slight dip between the main river bank and rand, but the latter usually rises rather steeply from the laggs. On some of the bogs short series of confluent eroded channels have developed on the rand sometimes as a result of cutting back by river or lagg. Small but steep erosion faces are sometimes present on the rand too." They noted that the vegetation of the rand was variable, typically with an abundance of *Molinia caerulea* which was particularly dense and tussocky at the base of the rand (i.e. its interface with the lagg. *Myrica gale* was also abundant in places on the rand. They also observed that "though the water table is near the surface, there is probably relatively rapid drainage down the rand". Boatman (1983) reported that, of his samples from the rand, two were allocated to the *Molinia–Myrica* nodum (steep gradient), one to the Molinieto-Callunetum and four to the Trichophoreto-Eriophoretum (low gradient). In the

[1] It should, however, be noted that patterns in this intrinsically species-poor vegetation may be expressed better in terms of quantitative rather than qualitative differences.

latter examples, the cover-abundance of characteristic species was generally lower than in examples from areas of patterned mire.

5.3.4 Lagg

On the Silver Flowe the laggs "are mostly quite narrow; sometimes merely a stream with no marginal swamp. For the most part they are swampy channels filled with tall, tussocky *Molinia* growing on a mixture of peat and alluvium" (Ratcliffe & Walker, 1958). They are typically some 2 m below the level of the adjacent ombrogenous mires. "Water can often be seen flowing between the *Molinia* tussocks but the main stream cuts deep into the peat and, in places, the underlying mineral material can be seen" (Boatman, 1983). "In places near the mouth of the lagg, where the gap between two adjacent bogs is fairly wide (as between Snibe and High Cornarroch) a kind of flush bog is often found. Such patches are dominated by Sphagna, usually *Sphagnum recurvum, S. palustre, S. plumulosum* and *S. papillosum* but often with abundant *S. imbricatum*, here in a lax, low hummock form different from the characteristic growths on the pool–hummock complex. *Molinia, Eriophorum angustifolium, Juncus acutiflorus* and *J. effusus* grow in the *Sphagnum* carpet in varying abundance

Streams which rise above the Silver Flowe, but which feed into the laggs, also seem to be called 'laggs' by Ratcliffe & Walker. "At one place where the southerly lagg of High Cornarroch Bog originates in the hillside blanket bog there is a basic flush, peaty at first but leading to an open stony patch drained by diffuse rills. Round the peaty edge of the mineral flush the usual *Molinia–Sphagnum* bog has much *Myrica, Carex lasiocarpa* and *Sphagnum plumulosum*, giving way to an open vegetation in the centre with very abundant *Scorpidium scorpioides, Drepanocladus revolvens, Campylium stellatum, Carex dioica, C. demissa, C. panicea, Phragmites communis, Drosera anglica and Potamogeton polygonifolius. Pinguicula vulgaris and Blindia acuta* are frequent and *Juncus articulatus, Triglochin palustre, Acrocladium* [*Calliergon*] *sarmentosum* and *Bryum pseudotriquetrum* occur occasionally. Lower down the lagg channel the rich flush effect fades, with a change to *Molinia, Myrica* and Sphagna, and some *Carex panicea*." (Ratcliffe & Walker, 1958). The cause of the base-enrichment was not identified.

5.3.5 'Blanket bog'

Ratcliffe & Walker (1958) commented on the 'blanket bog' vegetation on the hill slopes west of the Silver Flowe: "On the wet lower slopes of the granite range to the west of the Silver Flowe, Molinietum in some form predominates. Along the sides of sluggish streams, where there is periodic flooding and alluvial deposition, and on gentle drift slopes influenced by soligenous water, *Molinia* forms a dense tussocky growth with few associates other than *Myrica*. On steeper but still very wet slopes the grass shares dominance with other species to form a mixed bog community. *Myrica* is widespread chiefly at the lower levels, but *Calluna* (rather sparse) *Erica tetralix, Eriophorum vaginatum, Trichophorum germanicum* and *Narthecium* are abundant up to the summits. Sphagna are everywhere present, often as a major component of the ground layer: *S. papillosum, S. rubellum, S. subnitens, S. compactum, S. tenellum* and, in the numerous flushes, *S. subsecundum* vars. *auriculatum* and *inundatum*. Two bryophytes, *Campylopus atrovirens* and *Pleurozia purpurea* are distinctive members of this community. This blanket bog vegetation occurs on peat of varying depth, but usually on fairly shallow deposits which, nevertheless, are extremely wet." Boatman did not consider this hillslope vegetation.

5.4 Craigeazle Bog

Craigeazle Bog (NGR: NX 475 810) is the southernmost of the patterned areas and is on the east side of Cooran Lane. Ratcliffe & Walker (1958) considered that it "has the appearance of a typical raised bog, with convex shape, lagg streams, well-marked rand and central pool and hummock complex." The rand and lagg, however, is not continuous along the hillslope side and at one point the peat of the mire joins onto the adjoining hill slope.

Determinations of the sub-surface topography (Boatman, 1938) indicated the bog appears to be situated on a shallow spur from the hillside, around which Cooran Lane flows, but this is partly 'pinched off' from the hillslope by small valleys which penetrate some distance along the hillslope margin, both from the north and the south. This suggests that those stretches of lagg and rand that do occur along the hillslope edge of the bog are associated with these sub-surface topographical features.

The highest point of the peat surface is located eccentrically towards the north-eastern corner of the mire area (as delimited by the rand as mapped by Ratcliffe & Walker). There is a broad, but not exact, correspondence with this 'dome' of the mire and the sub-surface topography. South-westwards the peat surface forms a lobe sloping gently from a relatively flat surface associated with the highest point, and steepening in the vicinity of the broad marginal rand (by the river), but it does not apparently follow the irregularities of the sub-surface contours and can in that sense be considered to be partly independent of the underlying terrain. The western side of the mire appears to be developed over a relatively flat, if irregular, terrace.

On the main slope of the peat lobe, the hollows of the patterned surface tended to be arranged parallel to each other. At the upper, north-east, end, where the mire merges with the hillslope they formed a reticulum, and there were some differences in species composition, including a local prominence of 'pool Sphagna' (*S. cuspidatum*, *S. auriculatum*). It is not clear if this is because this area was flatter or because it receives additional water in run-off from the hillslope. Boatman considered that any water inflow might improve both the nutrient and aeration status of this top end of the mire (*Phragmites* was recorded from the lagg along the hillslope side). A corollary of this proposition is that at least the north-eastern section of the mire may be weakly minerotrophic. Boatman also provided evidence which suggested that the main area of hollows was located over a shallow sub-surface basin, and that the single deep pool (located near to the 'dome' of the bog) might be associated with a small sub-surface 'valley' that penetrated northwards from the south.

Ratcliffe & Walker (1958) found no evidence for a basal fen peat in a (single) core they reported from Craigeazle Bog, though there was some 25 cm of a "black amorphous peat". This seems to have helped to support their view that it was not a raised bog.

5.5 Snibe Bog

According to Boatman (1983) Snibe Bog (NGR: NX 474 818) "takes the form of a broad terrace lying between the lateral moraine at the foot of Snibe Hill to the west and the Cooran Lane to the east. The mire is about 0.75km long and about 0.25km wide. The middle section, about 0.25 km long, merges with the grassy slopes to the west, but the northern and southern sections are isolated from the hillside by streams. The northern section is broader than the rest of the mire because it lies within a bend of the river. The eastern part of this section forms a broad, uniformly-sloping rand."

"The majority of the pools are of the shallow type, with graded sides, and much of the area between them is occupied by hummocks. Compared with Craigeazle or Brishie mires, for example, there is relatively little *Sphagnum* 'flat'. The middle section forms the highest part of the mire and here the pools seem not to be orientated consistently in any direction. In the northern and southern sections, however, the pools are orientated predominantly in an east–west direction, parallel to the contours." (Boatman, 1983). Ratcliffe & Walker (1958) considered that the formation of the pool system was fairly recent, developing over a 'drier' community now at about 20 cm bgl, *viz.* a *Sphagnum* surface with *Molinia* and *Myrica*, and they suggested increasingly wet conditions. Birks (1972) subsequently observed that her pollen analyses suggested complete forest clearance of the hills corresponded with the onset of pool formation.

As mapped by Birks (1972), the main area of bog is largely surrounded by a rand, even along about half of the hillslope side. However, in the middle portion of the hillslope side no rand was mapped, and here the bog surface merges upwards into the hillslope, from which its edge appears to receive telluric water flushing downslope, marked by a local prominence of *Phragmites australis.*

Birks (1972) considered that "although it has the appearance of a typical raised bog, a levelled transect from west to east (Fig. 3) shows that it is not convex in this direction". However, Birks' section was located across the part of the bog where there was not a rand (as mapped by her) on the hill-slope side, possibly because at this point the bog-hillslope transition has been 'smoothed' by accumulation of peat under the influence of telluric water downflow. Had it been positioned further north or south it may well have displayed a convex profile. However, the rand on her section alongside Cooran Lane is clearly conformed by an underlying mineral ridge, and this may well have been the case along the entire riverside margin of the mire. It is possible that some "large mound-like islands" mentioned by Ratcliffe & Walker (1958) may be an above-surface expression of this same ridge.

Birks reported more than 5 m depth of peat, over gravel. There was no evidence of lacustrine sediments (*i.e.* of significant open water). In her Profile A the basal peat was highly humified peat with wood remains and some *Phragmites*, and *Phragmites* also occurred up to about 410 cm bgl. Above this was bog peat, which became less solid and humified upwards. Elsewhere in the basin, bog peat appears to have developed more directly upon mineral soil. Birks refers the lowest zone in her pollen diagram to a "*Betula–Corylus/Myrica* assemblage zone", but states that its age is unknown in the Galloway Hills.

Birks (1972) commented: "Ratcliffe & Walker (1958) did not recognize any fen deposits at the base of the Snibe Bog peats and concluded that the area was best regarded as a blanket-bog. However, fen peats are in fact present, so the bog qualifies as a raised bog in the sense of Ratcliffe (1964). However, bog peats directly overlie mineral ground around the bog margins, and the whole bog probably overlies several hollows which have all been united by the spread of ombrotrophic communities, so that Snibe Bog may best be described as an intermediate bog in a developmental sense (Ratcliffe 1964)." It may, however, be noted that the ridges within the main bog basin (on Birks' section) are low (1–3 m) and well within the range encompassed beneath sites elsewhere that are usually called raised bogs.

5.6 High Cornarroch Bog

Ratcliffe & Walker (1958) mapped a rand around most of High Cornarroch Bog (NGR: NX 473 825), except along the northern half of the western (hillslope) where it seems likely that a spur from the adjoining hillside runs beneath the north-west part of the mire. This forms the highest part of the mire, which here merges into the adjoining valleyside, and has a reticulate pool system. "South of this the pools lie parallel to each other and are extended in an east–west direction" (Boatman, 1983), probably across the main direction of slope, but surface topographical data are not available. On the southern part of the hillslope side, the mire is separated from the hillslope by a small stream, which flows around the edge of the rand and comes to separate this mire unit from Snibe Bog. Sub-surface topographical data are not available, and it is not known to what extent the rand reflects the topography beneath the bog.

As on Snibe Bog, *Phragmites* occurs where the main bog unit meets the adjoining hillslope, and spreads both into the head of the nearby lagg and into proximate pools and *Sphagnum* surfaces.

5.7 Craignaw Bog

Craignaw Bog (NGR: NX 471 830) is divided into north and south sections by a stream (Otter Strand). As mapped by Ratcliffe & Walker (1958), both sections are surrounded by a rand, except along the western (hillslope) side, and is not very clear why they have not been regarded as separate mire units. The southern section merges into the hillslope, but the northern section is partly separated from this by a small valley associated with a tributary of the Brishie Burn (though apparently without a corresponding rand along that part of the mire). The southern section is separated from High Cormarroch mire by a stream (Dow Spout) and its associated *Molinia* lagg and rands.

Boatman (1983) has reported peat erosion and slumping at the steeper edges of the mire. He considered that erosion associated with the Dow Spout and Brishie Burn tributary valleys was unlikely to be caused by stream erosion, whereas erosion along the eastern side is likely to be a consequence, at least in part, of erosion by Cooran Lane.

No detailed surface or sub-surface topographical data are available.

5.8 Brishie Bog

Brishie Bog (NGR: NX 476 834) occupies the bottom end of a gently south-eastward sloping tongue of peatland that drains from the vicinity of Long Loch, flanked on the south-west side by Brishie Bog and to the north-east by Saugh Burn. A relatively steep rand alongside Cooran Lane marks the southern end of the mire and curves around its sides near the delimiting streams, but it is not clear at what point the north-western limit of the mire (as opposed to the patterned surface) is supposed to be set. Ratcliffe and Walker (1958) commented: “That part of the pool–hummock complex most remote from the stream merges very gradually with the intermediate bog as the slope increases towards the Lochs of the Dungeon”.

A shallow valley in the peat extends northwards into the mire and partly divides it into two lobes. Both slope south-westwards and both support pattern surfaces, but whilst “deep and shallow pools predominate on the eastern lobe… the vegetation of the western lobe is mainly of the hummock–hollow type” (Boatman, 1983). Whilst some are not specifically elongated, the pools on the eastern lobes appear generally to run around, or across, a slope from the north-eastern corner to the sub-dividing valley. According to Boatman there are four swallow holes along the north-western side of the mire “where the patterned vegetation merges with that of the slope, one at the head of the valley which separates the two lobes of the patterned area and another amongst the fairly large isodiametric pools which lie on the north-eastern side of the eastern lobe”. They are marked by a surrounding ring of *Molinia caerulea* and are presumed to drain into a sub-surface drainage system. Boatman speculated that the peat valley may have originated by collapse of such a channel, and that any future collapse of a system associated with the north-western holes might result in the formation of a lagg-like structure between the patterned surface and the adjoining peat slope.

Examination of the sub-surface topography essentially showed that the highest ground was in the north-east corner of the area mapped and sloped irregularly to the south-west and south. Much of the more westerly part of the area was formed from either a broad trough or a basin (the feature extends beyond the limit of the area mapped and is exact character cannot be assessed). The lowest part is mostly beneath the western lobe of the mire, but from this "a broad valley extends approximately eastwards [partly] beneath the pools of the eastern lobe" (Boatman, 1983). Other than the general NE–SW slope, the surface topography shows little relationship to the underlying topography, and the steep rand has no relationship to this, and is most likely to reflect a limit imposed by Cooran Lane. Overall, the mire appears to bulge downslope towards the south-west and this is not entirely a feature determined by steepening in the area of the rand, as some of the higher surfaces towards to north-east corner tend to be flatter and have the most prominent pools. Upslope of the north-western edge of the patterned area, Ratcliffe and Walker indicated that the slope increases, but in the absence of peat depth data outwith the area examined by Boatman & Tomlinson (1977), it is not known to what extent this due to differences related to the peat surface or to the underlying topography.

The rand (and some of the adjoining area) was mapped as supporting "*Myrica* zone" and "*Molinia* zone" vegetation, and the higher upslope parts of the mire supported a "*Calluna* zone" vegetation, whilst the pools and the "*Sphagnum papillosum* zone" occupied a range of about 80 cm down the SW slope of the eastern lobe of the mire (Boatman & Tomlinson, 1977). It should, however, be noted that "most of the twelve species characteristics of the Trichophoreto-Eriophoretum are present in each of the zones" (Boatman, 1983).

Peat cores from the eastern side of Brishie Bog, taken both from beneath a hollow and beneath hummocks, point to depths of up to about 4 m bgl, all with a basal layer of wood (probably birch) peat. All of the peat was strongly humified, except near to the surface, but the peat composition suggested that conditions beneath the hollow had "been wetter than elsewhere almost throughout the development of the mire" Boatman & Tomlinson (1973).

5.9 Long Loch Bog B

There are three main areas of patterned mire near the head of the Silver Flowe (Long Loch Bogs A (NGR: NX 470 842) and B (NGR: NX 469 845), and Round Loch Bog (NGR: NX 467 846). They were considered to be similar by Ratcliffe & Walker (1958), and as detailed information is only available for Long Loch Bog B, attention will be focussed on this.

Ratcliffe & Walker describe these bogs as areas of patterned surface set within a much wider expanse of 'intermediate bog' and noted that none of them had an obvious rand or lagg. They "lie astride a ridge which extends approximately south-east from the col at the head of the valley" (Boatman, 1983). Long Loch Bog B has three groups of ridges and pools, separated by, and to some extent surrounded by, a hummock–hollow surface. The northern group of pools occupies the highest, and rather flat part of the mire surface, whence the higher ground associated with the ridge continues northwards. Another group is to the south east of this, on slightly lower, but again 'flat' ground, perched above a quite sharp slope eastwards. The third, south-west, group is slightly lower still, but appears to occupy a bench on the peat surface, below which is a quite sharp slope south-westwards. Levelled sections on the eastern side suggest that there is rather little difference between the amplitude of fluctuation of *surface* height between a non-patterned surface between Long Loch B and Brishie Bogs, a hummock–hollow area and the above-pool level surface of an area of pools (Boatman, 1983). The slope of the hummock–hollow area was also similar to that of the non-patterned surface.

There is a very general relationship between the height of the peat surface and that of the mineral ground, in that both peat and mineral surfaces are lowest in the south-eastern and south-western corners of the mapped area, but beyond that there is no clear relationship. Pronounced ridges, peaks and hollows in the mineral ground are not well reflected in the topography of the peat surface, nor are the steeper peat slopes on the south-east and south-west sides. Although these represent a drop in elevation of only about 1–2 m, the slope is sharp and it is not clear why this has not been considered to be a low rand. What is, however, clear is that the three main areas of pools are situated over basins in the mineral topography, and over deeper, but not necessarily lower, peat than elsewhere.

5.10 Implications for mire characterisation and typology

The mire units within the Silver Flowe all appear to be associated with areas of irregular terrain, where peat has formed over a mixture of small valleys and troughs and over hillocks and ridges. Within these areas, Boatman considers that patterned surfaces had formed in locations with topographical impedance to drainage and that "areas of hummock–hollow pattern tend to occur where the underlying mineral material forms a terrace, while areas of ridge–pool pattern overlie basins." However, no topographical data were presented for the large tongue of un-patterned mire between Brishie Mire and Long Loch Mires. Incidental comment suggests that the slope here was somewhat steeper than in the patterned areas, but there is no indication of the character of the sub-surface topography.

The four southern mires occupy a gently sloping (if irregular) valley bottom lined with hummocky glacial deposits and their hillside margins are at or close to the steeply-rising hillslopes. In most places they are separated from this by a stream or a lagg-like structure, but all appear to be connected to some extent to the hillslope by an isthmus of mineral ground, covered variably with peat. Whilst these mire surfaces appear generally to be ombrotrophic, it is possible that they receive some minerotrophic inflow from the hillslopes across the isthmus, and there is some floristic evidence (occurrence of *Phragmites* or prominent *Myrica*) which suggests that this may be the case. In some instances, *Phragmites* occurs in the marginal parts of patterned surfaces where these come close to the hillslope. The importance of such minerotrophic inflows to the hydrological balance and hydrochemical character of the mire units is not known; their penetration and influence may be quite small.

Boatman (1983) speculated at length on the type of mire represented by these sites without coming to any obvious conclusion. He pointed out that Sjörs (1965) "appears to believe that the patterned areas of the Silver Flowe resemble the eccentric mires of Sweden". However, Ratcliffe (1977) considered the Silver Flowe to constitute a "series of patterned blanket mires".

Various workers, including Ratcliffe & Walker (1958), have observed that Craigeazle Bog "had the appearance of a typical raised bog" (though topographically the word 'typical' is hardly appropriate). They discounted this assessment on stratigraphical grounds, apparently because "peat depth is relatively shallow and has not developed from lake or fen communities as in typical raised bogs" (though the depth of ombrogenous peat is not particularly shallow). Topographically, the mire has the appearance of a tilted raised bog, tilted broadly to the south-west. Wettest conditions are associated with the highest part of the surface, and the zone below (south-west) of this, which are the areas furthest from the main drainage points. Further downslope, towards the rand, as in a 'typical raised bog', the patterned surface is replaced by a somewhat drier, mostly unpatterned, surface. There is a well-developed rand and 'lagg' around much of the site, though along much of the eastern margin, where these features separate the mire from the rising hillslope, they are at least partly coincident with a small valley in the underlying mineral ground. Moreover, the highest part of the surface, towards the north-eastern end of the Bog is broadly associated with a ridge of mineral ground. This appears to form part of a small hillside spur, but topographical details of the transition of the mire to the hillslope are not available.

Snibe Bog has many similarities with Craigeazle Bog and was also considered to have affinities with 'raised bog' (Ratcliffe & Walker, 1958). Similar comment can be made as for Craigeazle Bog, though, being on the opposite side of the valley, the main bulge of the mire is broadly to the east. The sub-topography is known only from a single east–west section (Birks, 1972), which ran across the central part of the mire, joining into the mineral ridge that connected the area of bog with the hillslope. Birks' section demonstrated that the pronounced riverside rand was associated with a mineral ridge (that may run the riverside length of the mire) and that the sub-topography of the mire floor was undulating. She noted the affinities of the Moss to Coom Rigg Moss (Chapman, 1964a) and suggested a similar developmental mechanism. She also found evidence for basal deposits of fen peat in a deeper hollow. For the most part, the mire is separated from the adjoining hillslope by north- and south-running streams, which originate on the hillslope. It is not known to what extent their courses along the western side of the mire reflect the topography of the mineral ground or has been deflected by the accumulating mass of peat, but they are associated with lagg and rand along those sections of the western side of the Moss. It seems likely that if Birks' section had crossed the western lagg and rand then the peat surface would have had a more convex profile, though this appearance may well have been largely a consequence of the rand, not because of marked convexity associated with the main mire surface.

Brishie Bog and the northern Bogs occupy a different topographical context to the examples further south, though their characteristics are otherwise similar. They do not adjoin a steeply-rising hillslope but occupy a gently-sloping interfluve between two streams. Brishie Bog is at the southern end of this, where it is limited by Cooran Lane. There is a quite well-defined rand wrapped around much of the mire, associated with the delimiting streams, but not around its diffuse northern margin, where it adjoins the southern end of the large tongue of mire that extends up to the Long Loch Bog. Boatman (1983) has, however, speculated that some sort of lagg may be in the process of formation along part of this side of the mire, by the postulated collapse of peat pipes. The patterned surface forms much of the 'nose' of the interfluve and bulges towards Cooran Lane and the flanking streams. It is developed over an irregular topography but, other than a general NE–SW slope, is not obviously related to this. Nor is it obviously different from the surfaces of the mires further south.

Similar comment can be made for Long Loch Bog B. Ratcliffe & Walker (1958) did not map a rand here (but see Section 5.9) and the patterned surfaces appears to be embedded within a larger expanse of un-patterned mire. Unfortunately, no information is available concerning the characteristics (peat depth, sub-surface topography etc) of the un-patterned mire between Long Loch and Brishie Bogs.

The topographical context of the northern bogs at the Silver Flowe (*viz.* a gently sloping shallow interfluve) is comparable with that of Kentra Moss (Argyllshire), despite the large differences in physiographic context (inland glaciated valley *versus* coastal flat), and the mires themselves show many similarities. Yet Ratcliffe (1977) designated the one as 'blanket bog', the other as 'raised bog'. As it is hard to identify sensible differences between them *as mires* it is suggested that they all represent essentially the same ecohydrological feature. The Silver Flowe mires south of Brishie Bog are also very similar, though possibly more susceptible to weakly minerotrophic inflows because of their different topographical situation. It is suggested that they all represent essentially the same feature, for which the name 'bulging ombrogenous surface' might be appropriate [?]. [Or 'tilted ombrogenous surface'?]

5.11 References for Silver Flowe

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6 'Bog woodland' sites (Scotland)

The sites considered under this heading include a selection from seven disparate bog sites united by the fact that they are partly, and perhaps naturally, wooded (mostly by pine). They were examined in some detail by Wells (2001) and occupy "a bioclimatic gradient from the west Highlands through Speyside to the Black Isles". Their interest to the present project lies not so much in their likely status as 'bog woodland' (which was considered perceptively by Wells), but in the stratigraphical and ontogenic details that he provided. It should, however, be recognised that Wells' objective was not the provision of a detailed stratigraphical investigation of the sites considered. He recorded the stratigraphy of a number of peat cores from the sites examined. The cores were levelled and some of his cores were aligned into informal sections, but they were widely-spaced and can only provide a broad indication of stratigraphical and topographical variation.

The three sites excluded from much consideration here were those without a matching *NVC* survey (Inshriach) or those which appear to have been dug so extensively for peat that it is difficult to establish their original character from the residual surfaces (Inshriach, Monadh Mor, Mar Lodge).

6.1 Lòn Lèanachain

"Lòn Lèanachain is located *ca.* 11 km north-east of Fort William and is situated at about 120–130 m OD on the northern flanks of Aonach Mor overlooking the western end of the Great Glen (NGR: NN 198 786). The blanket, or intermediate, mire complex occupies an extensive area (*ca.* 125ha) of relatively level ground and is characterised by noticeable moraines at its western edge. Glacial silty boulder clays line a series of shallow basins within the moraine flats. This has provided a relatively impermeable seal over which peat has accumulated to form the mire complex" (Wells 2001). Wells has provided an *NVC* map based on a survey by J.M. Morris dated 1999, but any supporting quadrat data have not been seen. Unlike the other sites considered by Wells, the 'bog woodland' component at this site was provided by scattered birch rather than pine.

Some of the peat is fairly thin (< 2 m depth), humified and amorphous (*e.g.* near parts of the western margin). Elsewhere, peat depths are more typically between 2–4 m, often formed dominantly of *Eriophorum–Calluna* peat, in places with a cap of *Sphagnum–Calluna* peat. This is found in some areas mapped as M18a. The intersecting sections LL9–LL11 (south-north) and LL11–LL13 (west–east) suggest that the high point of LL11 may represent a 'dome' of peat that is at least partly independent of the underlying terrain, but as some of the cores are about 100–200 m apart, it is difficult to assess variation either in surface or sub-surface topography. Cores LL11–LL13 are all in an area mapped as M18a. By contrast, another area of M18a at site LL6 (on a north–south section LL5–LL8) appears to be a marked hollow (both surface and sub-surface), with a peat surface some 3.5 m below that of LL7. The upper 150 cm of peat here is described as "*Eriophorum/Calluna + Sphagnum*" and overlies a quite thick (190 cm) of wood and sedge peat. This location appears to represent a (probably paludified) depression (a basin or trough) within the mineral substratum which experienced a comparatively prolonged initial phase of telluric conditions. It appears to be a context in which a 'topogenous bog' or a shallow ombrogenous dome of peat could have accumulated, but more closely-spaced coring will be needed to establish its status. Another, more isolated, core (LL4) also has a cap of some 2 m depth of a variable, but not strongly humified, *Eriophorum/Calluna/Sphagnum* peat, over some 85 cm of wood and sedge peat. This, however, is underlain by thin bands of *Scheuchzeria* peat (15 cm) and a deposit with remains of *Potamogeton* and sedge (10 cm) which suggests an origin from swampy conditions or from shallow (and perhaps local) patches of open water.

Overall, Wells (2001) considered that "the peat drape generally tends to conform to the sub-surface topography (as in a 'classic' blanket mire) but also incorporates 'raised' peat lens subunits, while the whole 125 ha system is constrained by topography".

6.2 Loch Maree Islands

The Loch Maree Islands NNR consists of a group of islands in the north-western basin of Loch Maree, north of Talladale, centred on NGR: NG 910 735. Eilann Subhainn, Eilean Dubh na Srione and Garbh Eilean were examined by Wells (2001). Wells reported that:

> "The islands are low-lying (<50m OD) and relatively flat with frequent rocky outcrops delineating peat-filled basins filled by blanket mire communities. Mineral ground is generally occupied by closed-canopy pine woodland but many of the mires in between carry scattered pines of varying robustness …. The vegetation of the island group has been extensively studied, and has most recently been described in detail by Booth (1996) and Smedley (1998). The latter studies found the islands' vegetation to be dominated by three main *NVC* community types (M17a, M19a & W18d) together with numerous sub-divisions of these and smaller representations of other types, especially M18".
>
> "Peat depths vary across the islands from <2 to >5m. Generally, the peats found on Eilean Subhainn are deeper on average than on Garbh Eilean or Eilean Dubh na Sròine. The stratigraphy of the Loch Maree mires typically comprises a sequence of upper monocot peat (mixtures of *Eriophorum/Trichophorum* and other sedges) overlying *Eriophorum/Calluna/Sphagnum* peats, sedge fen peats and/or wood peats, above basal clays (or in some cases, bedrock). The survey thus establishes that many trees are established on substantial bodies of active mire and confirms the genuine nature of the 'bog woodland' existing in the islands. The existence of such a relatively well-wooded and stable mire ecosystem also gives lie to the oft-quoted assertion that 'blanket bogs in high rainfall areas have always been largely treeless' (Lindsay *et al*. 1988, MacKenzie and Worral, 1998).
>
> "The macrofossil diagrams illustrate the vegetation succession in two contrasting topographical mires. ES2 is from a pool system occupying a deep hollow in the topography and reaching 5m in depth, while ES6 demonstrates the biostratigraphy from a more 'typical' 2–3m deep area which possesses a drier surface. ES2 shows that peat formation began with open water communities with species such as Pondweed (*Potamogeton*) and Water Lily (*Nuphar*) together with sedges and fen bryophytes. This gradually became terrestrialised and eventually ombrotrophic conditions became established as peat accumulated sufficiently to raise the surface above the direct influence of groundwater, allowing the establishment of an M18 *Sphagnum/Eriophorum/Calluna* community which persists today. ES6 does not possess an open water or fen stage but comprises ombrotrophic mire communities from early stages, indicating the lateral spread of blanket mire by paludification."

6.3 North Rothiemurchus

The area of Rothiemurchus considered by Wells (2001) comprised six shallow hollows (basins or troughs) embedded within drier heath on a low interfluve between the rivers Luineag and Druie (at about NGR: NH 927 094) at around 250 m aOD. The hollows examined all supported M18 vegetation (*NVC* survey, I. Glimmerveen, 1995).

The stratigraphy of the depressions is dominated mostly by *Eriophorum–Calluna* peat, in some cores over a woody or sedge peat. Total peat depth was generally quite thin (often <2.5 m), in some (perhaps all) locations probably in consequence of former turbary. In a southern depression (Mire 1), mostly well-humified *Eriophorum–Calluna* peat was capped by a thin (< 1m) layer of fresh *Sphagnum–Calluna* peat, and the total peat depth in all cores was < 2 m. In nearby Mire 2 the peat was somewhat deeper (2.8–3.4 m total depth), with the deeper peat in the lower parts of the hollows.

Wells (2001) considered that the mires were best regarded as examples of ridge-raised mires, but with one exception (Mire 3) the 'ridges' involved seem to have been low, little greater than 2 m in height and it is not clear (from the sections provided) that the peat of each individual mire unit is not essentially confined within a single broad basin. However, Mire 3 is developed within a quite steeply-sloping peaty valley which falls by about 10 m (estimated from the stratigraphical diagram) south–north to the Luineag. The three peaty cores within this mire all had a well-developed basal wood peat, and it seems likely that this was originally a minerotrophic valleyhead, which came to support a sloping *Sphagnum*-rich surface. This had been mapped as M18 by Glimmerveen (1995), but it may be noted that this community can be difficult to distinguish from the closely-related M21 which, in England and Wales at least, is most typically associated with weakly minerotrophic percolation surfaces and soakways. The natural peat surface topography may have been much modified by turbary and the status of this peatland area is difficult to assess, or even to guess, without additional field data.

6.4 Pitmaduthy Moss

At about 50 m aOD and just off the north side of Cromarty Firth, Pitmaduthy Moss (NGR: NH 775 775) is a lowland, isolated mire unit of some 122 ha and of limited relevance to the present project but is included here because of the stratigraphical insights it provides into allied ombrotrophic mire systems of more 'upland' locations. It was examined by Wells (2001) and its vegetation was surveyed by R.J. Tidswell in 1994.

The Moss occupies an elongate, SW–NE-trending basin within Leinster Park. Wells commented that "Two broad vegetational divisions (between a western component dominated by wet, poor fen, fen carr and floating *Sphagnum* communities, and an eastern 'bog pine woodland' sector) can also be differentiated stratigraphically." It appears to consist of two basins separated by a shallow ridge capped by about 2 m of peat. The north-eastern basin is shallowest (about 3 m deep) and essentially supports a paludification sequence from a shallow minerotrophic deposit of some 20 cm depth capped by *Eriophorum–Calluna* layers with a variable contribution of *Sphagnum.* This area now supports relatively 'dry' M18 vegetation with numerous pines of mostly modest dimensions.

The south-western basin is somewhat deeper (about 4 m) and appears to be lined with gyttja, indicative of an initial open water phase and a terrestrialisation sequence. Gyttja is capped variously by wood peat and sedge peat which is in places covered by either *Sphagnum–Calluna* or *Eriophorum–Calluna* peat. There appears to be a hiatus at about 1.5 m depth at which these ombrogenous peats or, where it had persisted, sedge peat, are replaced abruptly either by a monocot peat or a deposit that was too unconsolidated to sample.

Wells (2001) considered it possible that the south-western basin had been affected by turbary, and that interpretation is consistent with the reported stratigraphy, assuming that peat digging was no deeper than about 1. 5 m. It is much less likely that the entire depth of the south-western basin was excavated, and the clear ontogenic differences between the two basins below 1.5 m bgl remain to be explained. It is of some interest that the different successional patterns in the two basins are reminiscent of differences between the twinned basins at Cors y Llyn (Radnor), which were described by Moore & Beckett (1971) and Moore (1978) and considered further by Wheeler *et al*. (2009). In terms of the categorisation proposed by these latter authors, the south-western basin at Pitmaduthy would probably belong to 'WETMEC 3: Buoyant weakly minerotrophic surfaces ('Transition Bogs')', whilst that of the north-eastern basin seems more similar to 'WETMEC 1: Domed ombrogenous surfaces ('raised bog' *sensu stricto*)', though this latter assessment really requires more field data (and may also be modified by further information gathered in the present project).

6.5 Implications for mire typology and characterisation

It is clear both from his stratigraphical sections and some of the comments of Wells, that different varieties of ombrogenous surface can be distinguished at some of the sites considered, ranging from thin(-nish) deposits that broadly follow the sub-surface contours to somewhat mounded surfaces that appear not just a consequence of the underlying topography. There are also intermediates between the two types. There is also some apparent tendency for the mounded surfaces to have a top-layer peat and vegetation that is richer in *Sphagnum* and which has been referred to the M18 community.

With the exception of Pitmaduthy Moss, no consideration has been made of the character and status sites which appear to have been heavily dug for peat, as it is unlikely that their 'natural' topography can be determined from the residual stratigraphical information. Such sites are, of course, actually or potentially important conservation units, and it is considered most appropriate that they are characterised by their existing surface conditions, not by reference to a presumed former, more natural, state. This has been illustrated by reference to Pitmaduthy Moss (Section 6.4).

6.6 References for 'Bog Woodland' sites

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7 Loch Shiel Mosses

7.1 Claish Moss

7.1.1 Site context

Claish Moss is a large area (about 4 sq km) of peatland on the south side of Loch Shiel, near its western end, roughly centred upon NGR: NM 719 679. It extends south from the shore of the loch into a broad embayment in the hills further south, and it is delimited east and west by spurs from these. Streams arising in these hills flow along the base of the uplands along the south-west (Dig á Bhogha) and eastern (Alta na Fasaidh Feàrna) sides of the mire. Other streams subdivide it into a series of three main sub-units[1].

The hills to the south of the mire merge eastwards into the western flanks of Beinn Resipol (846 m aOD) and typically rise to about 150 m aOD. They form a watershed with southward drainage into Loch Sunart. Claish Moss slopes gently northwards from the foot of the hills to Loch Shiel. Much of the Moss is encompassed within the 10 m contour, but near the shore it appears to be almost at sea level[2]. The several lobes of the mire occupy very shallow interfluves between the streams that drain across. In a few places the peat surface is punctured by small outcrops of rock, most notably Tom Liath.

7.1.2 Geological features

The geological features of the area are mapped on BGS Scotland sheet S52 (Tobermory). There is not an associated *Memoir.* The bedrock beneath the entire area is referable to the Moine Supergroup of the North Highlands Terrane, and mostly to the Morar Group of deposits. These consist of pre-Cambrian metamorphosed sediments. In places these are interrupted by narrow Palaeogene Dykes, mostly oriented north–south in the vicinity of the Moss, but none has been mapped under the area of the Moss.

BGS mapping shows Claish Moss as a large, and almost entire, area of Peat. 'Hummocky Glacial Deposits' have been mapped along the southern and eastern margins of this. These extend to a variable extent up the lower hill slopes to the south and to a possible, but unknown extent, beneath the mire. Glacio-fluvial deposits form a narrow fringe between the Peat and the Loch shore in the eastern part of the Moss, and also along the valley bottom of Allt na Claise, where it separates the eastern-most lobe of Peat from the Moss further to the west. It is likely that these deposits also extend beneath the Peat further west, but their extent is not known. A small Alluvial Fan has also been mapped associated with Allt na Claise, just south of the point where this enters the mire, and between the Peat and Glacio-Fluvial deposits of the valley bottom and the marginal Hummocky Glacial Deposits of the valley slopes.

Ratcliffe (1977) indicated that "Stratigraphical studies show that the mires developed over an extensive area of level ground, possibly a raised beach terrace, at around 25 ft.", but he gave neither supporting evidence nor attribution. 'Raised Marine Deltaic deposits' were not mapped here by BGS, as they were at nearby Kentra Moss (see Section 7.2). Stratigraphical transects provided by Moore (1977) across part of the site in the peat lobe east of Allt na

[1] Moore (1977) gave the area of the Moss as 1.5 sq km, but this would appear to refer just to the lobe he examined, between the two streams Allt na Claise and Dìg an Sgùlain.

[2] The 1968 winter water level of the Loch was given as 4 m above Newlyn datum.

Claise indicated a rather flat basal surface[1] underlain by sand and it is possible that these provided the basis for Ratcliffe's comment. In this part of the Moss at least, it seems rather likely that Peat is underlain by Glacio-fluvial Deposits, but this is not certain.

Bibby, Hudson & Henderson (1982) proposed that the sands and gravels beneath the peat in this Moss may be poorly drained due to "The presence of indurated horizons (probably in this instance due to pedological causes), horizons cemented by iron and manganese compounds in circulating ground waters, the formation of thin iron pans and the presence of occasional silt bands".

7.1.3 Vegetation and surface features

No *NVC* survey has been seen for Claish Moss, and in general details on vegetation and surface features are sparse. Substantial areas of 'patterned surface' are associated with each of the main lobes of peat, though they give way to a less variable surface close to Loch Shiel. They comprise, amongst other things, hummock–hollow complexes and arcuate ridge–pool systems aligned broadly across the direction of slope. Pools can be up to 100 m long, 10 m wide and 2 m deep (Moore, 1977). Hummocks are formed both of *Sphagnum* (including *S. fuscum* and *S. imbricatum*) and *Racomitrium lanuginosum.* Ratcliffe (1977) noted the affinity of the vegetation to the Trichophoreto-Eriophoretum.

Streams crossing and sub-dividing the peatland are flanked by a minerotrophic vegetation with much *Molinia*, but no further details are available. The landward edge of the mire is also flanked by a band of *Molinia*, often but not always associated with a stream. This may be regarded as a lagg-like structure, but no levelled profiles have been available to show the topographical relationship of the main areas of ombrogenous mire to the adjoining rising ground. Moore (1977) has pointed out that "*Phragmites communis* [*australis*] survives in moribund patches where the Moss abuts on to the lower slopes of Ben Resipol."

7.1.4 Peat stratigraphy and mire ontogenesis

Moore (1977) reported three stratigraphical sections from Claish Moss, none of them providing a complete section across the mire. All of them were in the section of the Moss between Allt na Claise and Dìg an Sgùlain; the longest was oriented south-east–north-west, towards the southern side of the mire. The sections show that the mire developed over a sandy base, probably Glacio-fluvial Deposits. It seems to have been initiated generally as a fairly thin layer of fen peat, present in most cores. Moore referred to this as 'marsh peat', but reported the occurrence of various species of *Juncus* and *Carex* which, with the presence of *Sphagnum teres*, suggested "a fairly high base status at that time". Moore's data counter the view expressed in Ratcliffe (1977) that "there is no evidence of any widespread development of fen conditions at the onset of mire formation". There was some evidence, in macrofossils and pollen, of aquatic species which "indicate that there were areas of open water, though the general stratigraphy of the area suggests that such pools must have been fairly small and shallow". It appears that the mire has developed more by paludification than by terrestrialisation. In some cores, the early 'marsh peat' was replaced by birch wood peat, which may also possibly represent a minerotrophic surface, but at its thickest the combination of marsh peat and wood peat seems to have been generally less than 50 cm. From his pollen analytical data, Moore considered the basal peat seems to have been initiated quite early in the Flandrian, perhaps between 9000–8000 BP. (Ellis & Tallis (2000)

[1] It is presumed that the surfaces of Moore's sections were levelled, but this is not stated.

came to a rather different conclusion for the nearby Kentra Moss (see Section 7.2), but did not comment on Moore's proposition for Claish).

The early fen or fen+wood peat was replaced by peat rich in *Eriophorum vaginatum* of variable thickness, but more than 1 m thick in places. Above this, at least in main central part of the mire (Transect 1), the peat was rich in *Sphagnum* (including *Sphagnum imbricatum*) and also *Racomitrium lanuginosum,* which has persisted to the surface. The inception of a patterned surface over the lower *E. vaginatum* peat seems to coincide broadly with the Elm Decline (about 5000 BP) (Moore, 1977). Depth of peat in these central areas was mostly just below 5 m in Moore's section. In this it seems that the reported northward slope of the mire surface reflects a gradual diminution of peat depth rather than a gradual lowering of the mineral base, but it is not known to what extent this generalisation applies outwith the area of the section.

Moore also examined the detailed relationship between components of the pattern surface along a short section. He concluded that all except one core had some evidence of pool detritus at some depth, suggesting periods of inundation, but even in the most 'pooly' cores there was no evidence for a pool persistent over a long period. Rather he considered that the profiles gave "the impression of a succession of overlying pools at this site, usually resulting from a swamping of the same general area of surface peat." The patterned surface, or at least elements thereof, appears to have been initiated early in the development of the mire, with the lower zone of *Eriophorum* peat.

Moore further examined a section closer to the Loch. Here, in the lowest areas, the peat was relatively thin (< 3 m). The early developmental stages ('marsh peat' and wood peat) were present, but were succeeded by an *Eriophorum–Molinia* peat, which gave way upwards to more than 1 m depth of *Molinia* peat.

7.1.5 Mire type

Both Ratcliffe (1977) and Moore (1977) regarded Claish Moss as a raised bog but noted its affinities to the 'eccentric raised mires' of parts of Scandinavia.

It is difficult to make any clear distinction between the character of the ombrogenous surfaces at Claish Moss and those at the Silver Flowe (see Section 5), other than in the greater prominence of *R. lanuginosum* in the vegetation and peat at Claish. Although Ratcliffe (1964) suggested that this might be a consequence of burning and disturbance, Moore's cores show that it has long been a characteristic component of the site. Its abundance here may well be a consequence of phytogeographical circumstances.

7.2 Kentra Moss

7.2.1 Site context

Kentra Moss is a large area (about 3.47 sq km) of peatland, centred on about NGR: NM 658 695, some 6 km west of Claish Moss (see Section 7.1) on the south-east of side River Shiel (the outflow from Loch Shiel) and close to the coast. The Moss essentially occupies a small coastal plain between the river and Kentra Bay, at not much above sea level. It is crossed by several roads and tracks and in places the peat surface is punctured by rocky outcrops. Ratcliffe (1977) considered that the site included "several raised mires", and various subunits can be identified (see Section 7.2.3 – Vegetation and surface features), partly delimited by roads and tracks. In part these follow the location of rocky outcrops and perhaps also strips of shallower peat.

Overall, the peatland occupies a shallow interfluve between the River Shiel (which drains into the outlet channel of Loch Moidart) and Dìg Bàn (which drains into Kentra Bay, and which separates the Moss from higher ground to the south). However, the south-eastern end of the Moss adjoins a low rocky ridge (some 50–100 m aOD), which separates the mire from Acharacle, whilst the north-western end of the Moss adjoins the higher ground of a rocky headland (Carn Mor, 122 m aOD) which separates Kentra Bay from the Loch Moidart outflow. In this area, a small part of the Moss appears to drain northwards, whilst at the south-eastern end there is some drainage southwards into Dìg Bàn. However, most of the Moss appears to drain roughly west towards or into Kentra Bay, and the overall slope of most of the site is reported as being east–west (Ratcliffe, 1977), across the 10 m contour, which is aligned more-or-less north–south.

Ratcliffe (1977) reported that "Much of Kentra Moss has been damaged by drainage and localised [mainly peripheral] peat cutting, but one section to the south-east of Arevegaig is almost undamaged."[1] However, Ellis & Tallis (2000) considered that "The central mire is predominantly undamaged *Scirpus cespitosus*–*Eriophorum vaginatum* blanket mire (M17 of the National Vegetation Classification; Rodwell 1991)". The 'central mire' is presumed to refer to the area which they studied, *viz.* north of the B8044.

7.2.2 Geological features

The geological context of Kentra Moss is similar that of Claish Moss (see Section 7.2.2). The geological features are mapped on BGS Scotland sheet S52 (Tobermory). The bedrock beneath the entire area is referable to the Moine Supergroup of the North Highlands Terrane, and mostly to the Morar Group of deposits. These consist of pre-Cambrian metamorphosed sediments. In places these are interrupted by narrow Palaeogene Dykes, mostly oriented east–west in the vicinity of the Moss, but none has been mapped under the area of the Moss.

BGS mapping shows Kentra Moss as a large, and almost entire, area of Peat, punctured by some rocky hillocks. Glacio-fluvial Deposits are mapped alongside the River Shiel near the eastern end of the Moss, and were said to underlay it by Ellis & Tallis (2000), but BGS mapping shows a fringe of 'Raised Marine Deltaic Deposits' (of gravel, sand and silt, but doubtless much supplied by glacial outwash from inland) around most of the Moss, and these probably underlie much of it, and in places have been exposed by peat removal around the margin of the mire.

Bibby, Hudson & Henderson (1982) have proposed that the sands and gravels beneath the peat in this Moss may be poorly drained due to "The presence of indurated horizons (probably in this instance due to pedological causes), horizons cemented by iron and manganese compounds in circulating ground waters, the formation of thin iron pans and the presence of occasional silt bands".

7.2.3 Vegetation and surface features

Kentra Moss supports several areas of patterned surface, in which pools and ridges are generally aligned roughly north–south. The different areas are separated by roads and tracks and appear to relate to separate hydrological sub-units of the site. The main area of mire, with the largest patterned surface is that between Kentra and Shielfoot, north of the B8044

[1] Most of the peatland area is north-east and north of Arivegaig.

road. Here the main patterned surface is partly separated into two lobes by a small valley which drains to the east and feeds a stream that flows into Kentra Bay. A lobe of the mire between the B8044 and the track to Arivegaig has a smaller area of patterning, located below (west of) rocky knolls near the intersection of the road and track. The third main area is in the southern corner of the mire, south-east of the track to Arivegaig, and developed below a series of rocky knolls that are discontinuous around its northern side. Many of its lineaments[1] are aligned NW–SE, but towards the eastern margin they trend NE–SW or even E–W. The two sets are separated at their southern end by a small trough which feeds souths into Dìg Bàn and this lobe of the mire appears to bulge southwards to drain along its southern boundary. However, there also appears to be drainage from its northern end along a stream which flows north-west below the area of patterned mire between the B8044 and the Arivegaig track and thence into Kentra Bay.

In addition to supporting a substantial area of M17, Ellis & Tallis (2000) also commented that "Ecological diversity is heightened by smaller areas of M1 (*Sphagnum auriculatum* bog pool), M2 (*Sphagnum cuspidatum/recurvum* bog pool), M6 (*Carex echinata–Sphagnum recurvum/auriculatum* mire), M15 *(Scirpus cespitosus–Erica tetralix* wet heath), M18 (*E. tetralix–Sphagnum papillosum* mire) and M25 *(Molinia caerulea–Potentilla erecta* mire) communities", but they provided no further detail. It is not known whether an *NVC* survey exists.

7.2.4 Peat stratigraphy and mire ontogenesis

No surface or sub-surface topographical data have been seen, though it is believed that a surface profile was levelled at a field meeting of the Mires Research Group. Ratcliffe (1977) commented that "The peat is generally shallower than on Claish Moss, averaging 3 m.", but provided neither data nor attribution. Ellis & Tallis (2000) recorded the macrofossil composition of four peat cores taken along a north–south line in the northern part of the mire between Kentra and Shielfoot, but they did not present any levelling data. Only one core (the northernmost) "comprised the full peat depth (396 cm)." Their main interest seems to have been to examine the relationship between stratigraphical changes and climatic shifts, and especially the value of oceanic ombrogenous peats in revealing these, rather than on the development of the mire.

Mire development at Kentra Moss seems broadly to correspond to that identified at Claish Moss by Moore (1977). Peat initiated seems to have started with a fairly short-lived phase of fen and wet (birch) woodland. However, a radiocarbon date of about 4430 cal. BP is much later than that suggested by Moore for Claish (based on pollen evidence), and fits with the time when blanket mire initiation was most widespread in Britain. Ellis & Tallis pointed out that the date is "roughly coincident with a mid-Holocene rise in sea level which occurred before about 4200 BP to a maximum height of about 7.7m OD… This event would presumably have washed away any pre-existing vegetation record from around Kentra Bay, so that the current low-lying peats would necessarily postdate the transgression maximum".

The upper boundary of the occurrence of birch twigs was associated with a significant decrease in peat humification (about 4070 cal BP) and an increase in *Eriophorum* in the peat, There was also charcoal in the peat just below the transition to apparent ombrotrophic conditions, which may partly obfuscate attribution of the change just to a wetter climate. Remains of Sphagna generally become important higher in the profile, in sequence *Sphagnum* sect Acutifolia, *S. papillosum* and *S. imbricatum. S. imbricatum* was subsequently

[1] Linear features

lost from the macrofossil records at about 1400 cal. BP, and is thought no longer to occur on the site. Ellis & Tallis suggest that this could be in response to increased wetness of the mire surface, being replaced by *S. papillosum* and *Racomitrium lanuginosum*.

7.2.5 Mire type

Ratcliffe (1977) observed that “Kentra Moss is the name given to several raised mires occupying the low-lying coastal flats between Kentra Bay and the River Shiel”. By contrast, Ellis & Tallis (2000) designated it as a blanket mire, seemingly because it occupied a topographical and climatic context in which oceanic blanket mire could well occur, not by reference to the characteristics of the peat deposit itself.

It is not known, because of lack of information, to what extent variations in sub-surface topography has been important in differentiating the various sub-units of the Moss. Its location on ‘Raised Marine Deltaic deposits’ might suggest a flattish underlying surface, but the presence of rocky knolls protruding through the peat, such as those which form a broken semi-circle around the northern end of the south-eastern part of the mire, point to greater sub-surface variation, at least in some places.

It is difficult to identify any significant typological difference between Kentra Moss and Claish Moss.

7.3 References for Loch Shiel Mosses

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8 The Flow Country

8.1 Introduction

The name 'Flow Country' has come to be given to a large tract of mostly rather low altitude, gently undulating land in Caithness and east Sutherland which is extensively covered with peat (Lindsay *et al.,* 1988). Ingram (1987) considered that the mires of the Flow Country together "comprise what is probably the largest tract of contiguous mire which still survives relatively intact in Western Europe".

Lindsay *et al.* (1988) explained that 'flow' was "a northern term for any flat, deep and wet bog". The *Oxford English Dictionary* considers that its derivation is probably from the Old Norse **flówe* and gives a definition based on Jamieson's *Etymological Dictionary of the Scottish Language* (1808–1880) as "a watery moss, a morass". The *Scottish National Dictionary* emphasises the wetness and fluidity of the flows, and includes a quotation from Caithness, dated 1795: "In many of these morasses or flows, as they are here called, when the surface is bored, the water issues out like a torrent with great force." Likewise, Lewis (1905), with reference to the mires of lowland Wigtownshire (including the Flow of Dergoals, Knock Moss and Annabaglish Moss), observed that: "Many of the mosses are of the nature of flow mosses, merely consisting of a crust of peat firmly bound together by the wiry stems of *Myrica gale*, *Calluna* and *Scirpus*, underlain by many feet of semi-liquid peat, and I found it was impossible to cut sections in such cases, and had to fall back on borings in order to obtain specimens of the basal peat layers and underlying glacial deposits." Since then, Boatman (1983), concerned with the Silver Flowe (see Section 5), equated 'flowes' with 'patterned mires'[1], an approach which seems broadly, but not exactly, concordant with the view of Lewis, and which draws particular attention to the sometimes spectacular patterning of pools that occupies the surfaces of some of the wettest parts of these mires.

Despite the undoubted ecological and conservational interest of the 'Flows' they have generally been rather little investigated, and there appears to be a particular dearth of simple, basic topographical and stratigraphical data of the sort needed to characterise the components of these peatland systems and to provide a preliminary assessment of their likely ecohydrological characteristics. However, *NVC* surveys are available for a number of the sites, and at some locations detailed investigations have been made to examine particular issues, such as pool formation and hydrology (*e.g.* Smart, 1982; Belyea & Lancaster, 2002; Holden *et al.*, 2018). On a broader scale, Lindsay *et al.* (1988) recognised a number of distinctive 'site types', but these were essentially just composite vegetation units, based jointly on species composition and its spatial organisation (physiognomy). In general, none of these studies has provided much documented information and insight into the ecohydrological character and development of the mire systems within which they were made. An exception to this generalisation is provided by the detailed and informative work of Charman (1990–1995) (see below), though he was concerned particularly with one of the more esoteric features of the region – the occurrence of rather small but striking

[1] "the vegetation forms impressive mosaics consisting of a mixture of *Calluna*-dominated hummocks, *Sphagnum* carpets, sedge lawns, shallow *Sphagnum*-dominated hollows and deep permanent pools. Such areas are sometimes called 'patterned mires' and in Scotland are known as 'flowes'" (Boatman, 1983).

scalariform[1] fens within the blanket mire landscape – rather than with the development of the main ombrogenous mire complexes, though he does provide valuable information relevant to some of these.

Lewis (1906) investigated the peat in the area near Altnabreac (Caithness), but this was an outlier to his national composite 'sections' of bog stratigraphy. His main interest was in identifying layers of contrasting botanical composition within the peatlands and their geographical variation across Scotland, and he recognised, amongst other things, the fairly consistent occurrence in some locations in the north of mainland Scotland of one or two *Pinus* layers within the peat (Lewis, 1907). Whilst he gave some details of the peat stratigraphy in the Altnabreac area, he provided no topographical sections, either for the peat surface or the mineral sub-surface.

In a rather discursive, and recognised incomplete, contribution, Pearsall (1956) considered "two Blanket-Bogs in Sutherland": Druimbasbie Bog and Strathy Bog. He provided some details of their surface features and topography, and some limited sub-peat topographical information. These are described below.

8.2 Druimbasbie Bog

This site, part of a larger area of peat, is located at about NGR: NC 765 634 at just below 150 m aOD, and was examined by Pearsall (1956). Much of the mire has developed on what appears to be a 'saddle' of very gently sloping ground, within a shallow col that falls away to the north and south between a very low ridge to the west and the somewhat greater and steeper slope of a low (160 m aOD) hill to the east. The 'crown' of the mire is in the south-east corner where "extremely gentle slopes" support a patterned surface, including two large pools. North-west of these, a lower, visually 'flat' area supported "a maze of pools", with a series of 'furrows' containing pools and separated by ridges, mainly to the west of these and mostly aligned across the gradient of a shallow slope. On the more strongly sloping north and south ends of the mire, Pearsall mapped erosion complexes, whilst much of the western (and probably 'drier') side had been dug for peat. A SE–NW section across the bog, quite close to and more-or-less parallel with the steeply-sloping ridge to the east, indicated that the pool systems were associated with benches on a shallow NW-trending slope, whilst a shorter section made orthogonal to this suggested that at least part of the pool system was associated with a depression in the sub-peat topography (which may have been either a basin or a trough) (sub-surface topography was not shown on the main SE–NW section).

8.3 Strathy Bog

Strathy River Bog (at about NGR: NC 803 530), on the west side of the Strathy River at about 130 m aOD, was described by Pearsall (1956) as a relatively small site, "roughly pear-shaped in plan and sloping gently downwards towards the north-east from the higher and narrower south-westerly end of the pear. The broader and lower end drains almost directly into the

[1] These areas of minerotrophic mire are marked by a strongly ridged, ladder-like surface. Lindsay *et al.* (1988) referred to them as 'ladder fens', but they are not very comparable globally with the much larger 'ladder fens' of eastern Canada. Probably recognising this, Charman (1995) referred to them instead as 'patterned fens', but this is a generic term which can encompass various forms of fen surface. Here the term 'scalariform' (= 'ladder like') is used, specifically to refer to the configuration of the fen surface and without wider implications.

Strathy river and the upper margin receives some drainage from shallow peat below the adjacent wet heath of *Calluna, Trichophorum, Erica tetralix.*" The surface of much of the south-west (highest) half of the mire is almost flat but is slightly domed (by about 30 cm). Around this area, except on the hillslope side, the surface falls steeply by about 2 m to form the riverside slope of the 'bulge' of peat. Thus in N–S section it appears as a quite steep sided, prominent dome of peat; in W–E section it is more like a half-dome, pressed against the rising hillslope on the western side. In the SW corner there was a large, roughly circular pool, but north-eastwards were a large number of 'furrows' (narrow, shallow elongate pools) aligned similarly across the slope. However, the steep slopes around the lower margin of the mire, and by the river, were described as being an unstable erosion complex. Two drainage lines were present, on the NW and SW side of the bulge, separating it from the hillslope and intercepting water seeping from this. Pearsall considered that a local prominence of *Myrica gale* and *Eriophorum vaginatum* occurred "in areas where water seepage from other places is observed", a proposition which begs a number of ecological questions, and includes the possibilities of greater water flow and better drainage, both perhaps associated with the drainage lines.

The stratigraphy was described along a SW–NE section as a "very wet" peat some 4 m depth over a basal layer with wood. However, the peat at the hillslope margin was thin, and its base generally sloped more steeply than its surface down to the position of the steep edge of peat and erosion complex that formed the riverward margin of the mire. Thus, the deposit appeared rather as a 'bulge' in section as well as in plan.

NVC surveys made in 1993 and 1997 are available for Strathy Bogs (Golspie Peatland Team (Nature Scotland)). Large areas mapped as a form of M18 in 1993 were mapped as a form of M17 in 1997. It is suspected that this may relate more to different perceptions by the surveyors than to significant vegetation change between these years, but no relevant information (quadrat data etc.) has been available.

8.4 Cross Lochs

The Cross Lochs peatland occupies a large area of the north-eastern end of a broad, spur-like ridge which falls in steps north-eastwards from Ben Griam Beg (580 m) (NGR: NC 832 941). Peatland occupies both the top and the slopes of the ridge. The top of the ridge in the Cross Lochs area is marked by five large lochs and numerous lochans, and contains substantial areas of 'patterned mire', on flattish ground, more-or-less enclosed by the 180 m contour. This area drains both east and west, to the Halladale River and River Dyke, respectively, and also north-eastwards, down the nose of the ridge towards their confluence. The slopes are mostly peat-covered, and are largely forested along the western side and around the nose of the ridge. The peat is generally regarded as being ombrogenous, but on the eastern side of the ridge there are two areas of soligenous fen embedded within ombrogenous peat, and marked by a scalariform patterning that is distinct from that of the patterned ombrogenous mire over and near the top of the ridge.

Charman (1992) examined the stratigraphy and initiation of blanket bog in (mostly) forested ground on the north-west side of the watershed. His section followed the line of a forestry track which crossed, partly obliquely, a fairly gentle, north-west-trending slope. Much of the section consisted of sloping, fairly shallow (about 1 m depth?[1]) peat, interspersed with several small, shallow hollows with somewhat deeper peat (up to about 3 m depth?). One

[1] Peat depth is generally difficult to determine from the small-scale diagrams of sections provided by Charman (1992)

peat core was reported from shallow peat at the top of the section. The other three were from somewhat deeper 'basin' locations. Radiocarbon dating indicated that the earliest peat formation was as a fen peat in hollows on the lowest and mid-range part of the section slope, at around 9000 BP, whereas at the top of the slope ombrotrophic peat initiation appears to have occurred more-or-less directly across a paludifying surface, dated at around 6800 BP in a shallow hollow and at around 4000 BP in a nearby, better-drained, location. Ombrogenous peat, or something like it, appears to have replaced minerotrophic peat in the mid-slope and bottom hollows, at perhaps around 0.5 m and 1 m bgl respectively, but these transitions were not dated. Despite an absence of the 'cultural indicators' found in some other locations, Charman (1992) considered it likely that peat initiation was associated with some human impact (some Mesolithic forest clearance and episodic burning), and that "the role of climatic factors remains equivocal".

An *NVC* survey (dated 1992, Golspie Peatland Team mapped most of the peatland on the flatter surface of the ridge as M18 (Figure 11). In places, particularly on more strongly sloping ground, there was a tendency for this to be replaced, sometimes transitionally, by M17 and M15 (rarely M19). At the south-west end of the top of the ridge, this occurred as part of the steeper, stepped slope rising south-westwards to Cnoc Bad an Amair (233 m aOD), and it was also the case along much of the steeper parts of the south-eastern slope of the ridge. However, in the lower part of the eastern slope, in the area north of Ewe Burn, M18 was mapped widely, particularly in shallow east-draining valleys and troughs separated by small ridges that mostly supported M15 vegetation. South of the Ewe Burn a similar vegetation pattern was found, with M17 on the generally-steeper slopes and M18 across the top of the nose of a separate, north-east-plunging spur west of Forsinard.

In the 1992 *NVC* survey, the two areas of scalariform fen were mapped as 'FC35', a non-*NVC* unit that had been created and called "*Carex rostrata–lasiocarpa* mud-bottom hollows" by Lindsay *et al.* (1988). These 'mud-bottom hollows' are separated by narrow ridges, which may belong to a different community in the scheme of Lindsay *et al.*, but this is not evident in the (coarser) *NVC* mapping. Lindsay *et al.* (1988) did not state how their units were derived[1] but noted that they were "described according to species constancy rather than abundance as is usual in such phytosociological tables". Subsequently, Charman (1993) allocated the pools to his TWINSPAN-derived *Sphagnum auriculatum* or *Carex limosa* noda, and the ridges to his 'typical' *Sphagnum papillosum* ridge nodum. He pointed out that the *NVC* scheme has no near equivalent for his *Carex limosa* nodum.

The north-eastern patch of scalariform fen examined (Cross Lochs B; NGR: NC876 467) drains almost due north. South-east of this, the eastern patch (Cross Lochs A, NGR: NC882 459) drains to the east. The two areas of fen are about 0.9 km apart, separated by a broad swathe of ombrogenous mire, much of which has been mapped as M18 by the Golspie Peatland Team (Figure 11).

[1] Elsewhere in the same document it is stated that in another analysis of surface patterning, vegetation units were derived from a TWINSPAN analysis of the vegetation data, and from these, noda were selected based on whether or not they related to field vegetation patterns observed on aerial photographs. It is not clear if the larger vegetation units were also somehow based upon TWINSPAN analyses.

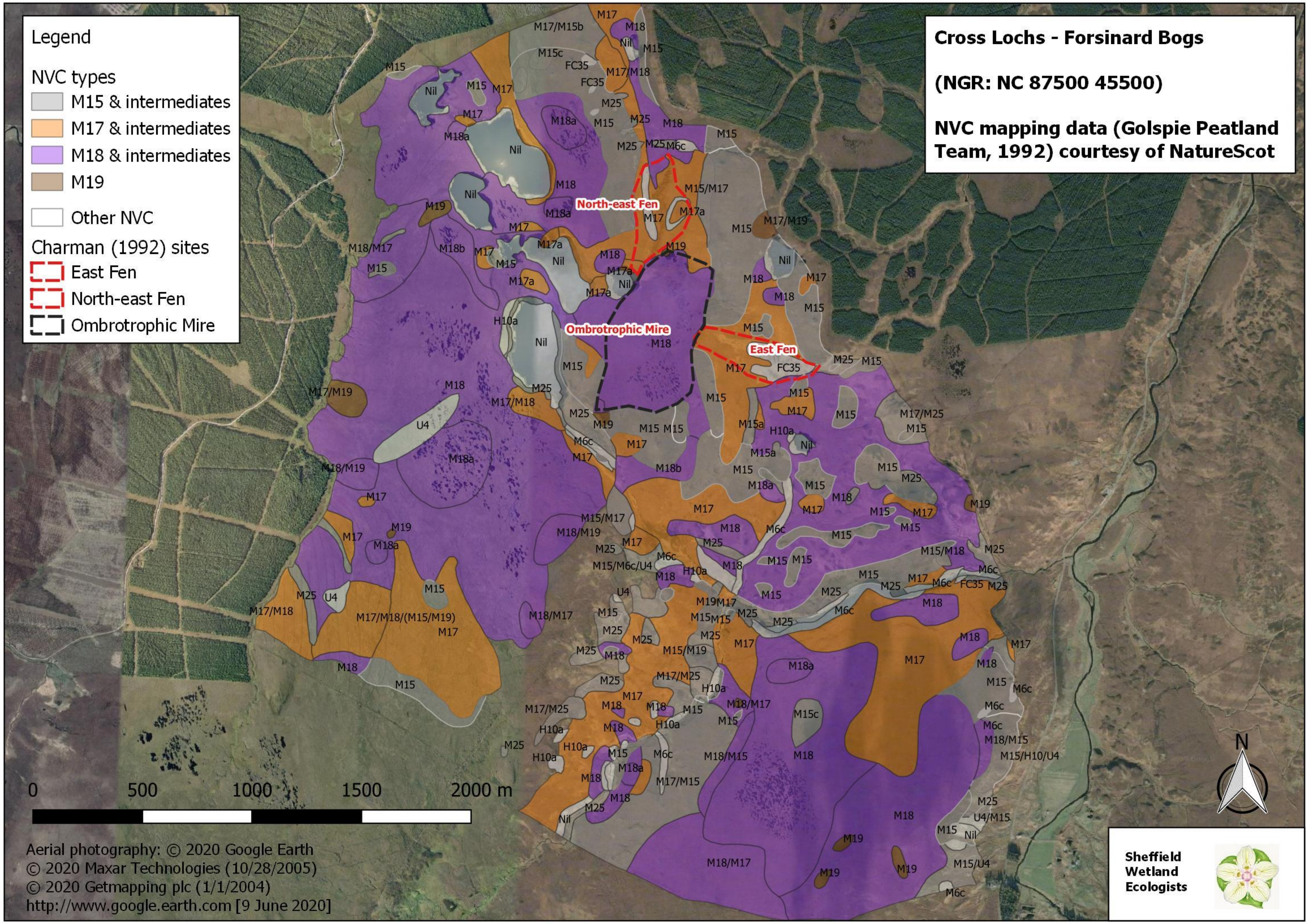

Figure 11. Cross Lochs *NVC* map and locations of Charman (1992) study sites.

8.4.1 Cross Lochs East Fen [Cross Lochs A]

This strip of soligenous fen (at NGR: NC883460) was investigated and considered by Charman (1990, 1994a). It occupies the rather gentle, eastern slope of the Cross Lochs ridge, between about 160–170 m aOD. Aerial photographs suggest two main strips of scalariform fen, of which the northern strip is the most prominent, that join downslope. The sub-peat topography indicates two small valleyheads in the mineral ground, which also join downslope, but the patterned fen surfaces do not correspond well with these (they are located partly over the small, low sub-peat spur which separates the sub-peat valleyheads). Charman (1994a) stated that there is a small spring at the head of the patterned fen.

A longitudinal section provided by Charman down the length of the patterned fen indicates a fairly gentle hill slope which contains at least two quite deep depressions (3+ m depth) separated by shallower peats, mostly thinner than about 2 m. The deepest basin (and peat) was at the bottom of his section and provided the site for radio-carbon dating and detailed macrofossil analysis. A transverse section proved a spur between the two valleyheads, and also showed that – at the point of this section – the surface topography was a subdued reflection of the sub-peat topography.

Stratigraphical details provided by Charman suggest that the gullies and depressions in the mineral ground initially supported areas of fen which, he considered, accumulated between about 9400 and 6200 BP. This appears to have formed a fairly typical valleyhead fen, such as might be expected in such a topographical context, though it is not known to what extent it was fed by down-slope flow of surface water or by groundwater outflow. Charman considered that “the extension of the peat body proceeded gradually upslope” but, apart from the fact that his lowest peat core, near the bottom of the valleyhead, was the deepest and had the oldest date of initiation, the upslope sequence of decreasing peat depth and initiation dates was variable, reflecting the topographical heterogeneity beneath the course of this longitudinal section.

Ombrogenous peat appears to have developed over the spur between the two valley-heads, and on adjoining surfaces, between about 5300 and 3500 BP, either more-or-less directly upon the mineral soils or after a short interpolated phase of woody peat. Ombrotrophic conditions also began to become established, but less sharply, over the fen peat within the original gullies and hollows. It is not clear, from the data provided, just when this occurred, because of the fuzziness of the transition. In the deepest core, taken from the bottom end of the fen system, there is an abrupt increase in the remains of *Erica tetralix* between about 220–140 cm bgl, dated as starting at around 5900 BP, and forming a rather woody peat, followed by a short-lived zone with much *Eriophorum vaginatum* (from about 4250–3920 BP). In neither zone did the peat contain much recognisable *Sphagnum*. The *E. vaginatum* phase may well be indicative of ombrogenous conditions, but whilst the preceding *E. tetralix* / woody peat probably indicates the establishment of drier surface conditions, these were not – based on the macrofossil evidence – necessarily ombrotrophic, although Charman (1994a, 1995) seems to have considered them as such. Based on the diagrammatic cores provided by Charman, it appears that in a few cores (*e.g.* 5, 9 and 10) there is no certain evidence for an ombrotrophic layer at all, though all of them have the apparent ericaceous / woody layer.

The development of the upper layer minerotrophic fen peat, which more-or-less continues to the surface, is a relatively recent event, and started between about 70–90 cm bgl in many of the cores. It is suggested that this was at about 2850 BP and was marked by “a uniform change back to poor fen sedge peats” (Charman, 1994a). At the very top of the cores there is a thin, and possibly very recent, deposit of peat, in which *Sphagnum papillosum* is a significant component. It is not clear to what extent there has been a corresponding reduction in 'minerotrophic species' across all of the fen surface at the time of this most recent deposit, or whether this change relates more specifically to the development of ridges within the area of fen. In the more peripheral cores (the margins of the transverse section and the uppermost cores of the longitudinal section), the entire surface 'fen' deposit appears to be thin (about 20–30 cm).

Charman (1994a) pointed out that the wettest part of the mire, with the best-developed surface patterning, does not coincide with what might have been expected to be the wettest locations based on the sub-peat topography, and contrasted, for example, with observations by Boatman *et al.* (1981) (and Boatman, 1983) on ombrogenous mires at the Silver Flowe (see Section 5). However, the patterning of the fen surfaces is different in character to that described from these ombrogenous sites, and there seems no reason why their causation and origin in these soligenous mires should be the same as in ombrogenous patterned surfaces.

8.4.2 Cross Lochs North-East Fen [Cross Lochs B]

This narrow strip of soligenous fen (at NGR: NC877467) was investigated and considered by Charman (1990, 1995). It occupies the rather gentle, north-eastern slope of the Cross Lochs ridge, at around 180 m aOD, and slopes towards the north-north-east, but for much of its length it is located alongside (below) steeper ground to the west. Charman has suggested that there may be groundwater outflow from this slope into the western margin of the fen area.

Charman reported a longitudinal section located specifically along the length of the patterned fen, and three transverse sections. Of these latter, the top two extend eastwards beneath a quite large area of flanking ombrogenous mire, and in that area their stratigraphical details relate to this rather than specifically to the patterned fen. Overall, the sub-peat topography indicates a quite broad, sharply incised valleyhead, varying in depth down its length, in places encompassing small depressions which initially contained (mostly shallow) water. Much of the strip of patterned fen is positioned asymmetrically towards the western margin of this sub-peat valley and is not necessarily over the deepest parts of the original valley.

Charman's stratigraphical cores here seem somewhat less well characterised than those from the East Fen (see Section 8.4.1), and were not directly radio-carbon dated, but could be related to a nearby radio-carbon dated pollen core (Charman, 1994b). They essentially suggest a similar developmental sequence to the East Fen. The bottom-most, deepest core was taken from what appears to have been a basin within the valley and has basal limnic deposits. On top of these, an early phase of what seems to have been a rather acidic seral fen with birch was replaced, rather fuzzily, by an apparently ombrotrophic surface, which was itself subsequently replaced by resurgent minerotrophic conditions and development of a monocot peat, perhaps at around 2700 BP. As at the East Fen, there appears to be an increase in *Sphagnum* at and near the surface in relatively recent times.

Elsewhere along the length of the fen, as shown by Charman's longitudinal section, the peat is generally thinner (about 2.5 m depth), though with a deeper deposit in an apparent hollow at the upper (southern) end. A feature of all the cores along the longitudinal section is that the layer of apparent ombrogenous peat is mostly fairly thin, in some instances less than about 1 m thick, and in one particularly shallow core [3], apparently atop a small ridge, it appears to be absent altogether. Likewise, the transverse stratigraphical sections show little evidence for ombrotrophic peat along the western margin of the strip of fen.

Away from the strip of patterned fen, towards the eastern slope of the buried valley, there is generally little evidence for minerotrophic conditions, either at the top or bottom of the sequences. At the base of these cores, ombrotrophic conditions appear to have developed directly over mineral ground or over a wood-rich peat. At the top end of the strip of fen, where the topographical valley becomes less evident, the area east of the fen merges into that of the 'ombrotrophic mire site' (below).

8.4.3 Cross Lochs – ombrotrophic mire site

A quite large area of apparently ombrogenous mire (NGR: NC877460) was investigated and considered by Charman (1990, 1995). It occupies the area between the two fen sites (see Sections 8.4.1 and 8.4.2 above), on the rather gentle, north-eastern slope of the Cross Lochs ridge, at around 170–180 m aOD, and slopes broadly towards the north-east. The sub-peat topography indicates that this mire occupies a quite broad valleyhead, which becomes more sharply defined down its length, and varies irregularly in depth lengthwise. In places it encompasses small depressions which were once water-filled. This valleyhead appears to be continuous with, and to form the upper end of, the valley within which the North-east Fen site is located, somewhat further down. It is separated from the East Fen site by a peat-covered, sub-surface ridge of mineral ground, but over much of the ombrotrophic mire area this is not reflected at the surface, and the peat surface tends to slope gently eastwards, across the ombrotrophic mire and over the ridge into the East Fen 'catchment', as well as northwards, down the course of the sub-peat valley.

Peat cores from the lower valley-bottom part of the ombrotrophic area suggest, perhaps not surprisingly, a similar early developmental sequence to that recorded in sections from the nearby North-east Fen. Except where there were basal limnic deposits (of possible late-Devensian origin), much of the earlier valley infill was minerotrophic in character, apparently a type of wooded (birch)–sedge fen. This was replaced by a cover of apparently ombrogenous peat but, unlike in the scalariform fen sites, this has persisted to the present-day surface. There is, however, some stratigraphical variation in the ombrogenous peat.

A core taken for detailed macrofossil analyses, collected from the area of a former (late-glacial) pool, showed a fairly abrupt transition from a sedge-rich monocot peat to an apparently ombrogenous peat with woody remains and remains of *Eriophorum vaginatum.* Charman (1995) dated the onset of ombrogenous peat in the macrofossil core to around 6050 BP (Charman, 1994b). In the macrofossil core, but seemingly not in any others, this layer of ombrogenous peat was replaced upwards by a peat "dominated almost completely by ericaceous dwarf shrubs" (Charman, 1995). In some cores, in "the part of the mire that is wettest today", there was a distinctive "stratigraphy in the top 1–2 m, with *Sphagnum* peats, some ericaceous remains and *Menyanthes trifoliata* seeds evident in the field". In the macrofossil core, Charman (1995) dated this change, indicated by "a marked expansion of *Sphagnum*, mostly *S. imbricatum*, from 2700 yr BP and a further change to a more diverse *Sphagnum* community from 1470 yr BP". This wettest area, with a surface labelled as "Wet *Sphagnum* dominated with pools", has developed over former limnic deposits and occupies a basin within the valleyhead, as evidenced by Charman's longitudinal section. The transition at about 2700 BP to a more *Sphagnum*-rich peat was "stratigraphically linked to changes across the whole of the site, all of which indicate increased surface wetness. This suggests a similar transition to that found in many raised mire stratigraphies throughout northwest Europe…. [which] is generally attributed to climatic change and an increase in precipitation / evaporation ratios."

In contrast to the basins and hollows, the ombrogenous slopes that surround the former valleyhead have little or no evidence of an early minerotrophic phase and consist of a generally thinner, rather nondescript peat, with *Eriophorum* remains and woody fragments, that has developed more-or-less directly over mineral ground. The date of initiation of ombrogenous peat on these slopes is not known with any certainty but, by analogy with data from the East Fen area, Charman (1995) suggested that a "peat cover was probably not complete until at least 3500–4000 yr BP."

8.5 Water Supply Mechanisms

8.5.1 Hydrogeology

The Cross Lochs peatlands are located at the junction of four 1:50,000 sheets of the British Geological Survey (BGS) for Scotland. The Cross Loch ridge and western slopes fall across the north edge of BGS Sheet SC109W (Badanloch) onto the south edge of BGS Sheet SC115W (Strathy Point), whilst the lower eastern slopes are represented on BGS Sheets SC109E (Kildonan) and SC115E (Reay). As mapped by BGS, the bedrock of the area around Cross Lochs is formed from metamorphic sandstones (psammites) and mudstones (pelites). These form part of the Moine supergroup of rocks and comprise much modified Neoproterozoic marine sediments, deposited between about 1000–870 Ma[1] (Strachan *et al*., 2002). Several areas of exposed bedrock have been mapped by BGS, particularly near the crest of the ridge, and including an area near or at the top end of Charman's longitudinal section across his selected stretch of ombrotrophic mire. Such 'exposures' may well be covered by thin, un-mapped peat (*i.e.* thinner than the BGS mapping depth). The Moine psammites and pelites are unlikely generally to be significantly water-bearing, except along fissures. It is possible, but not known to us, that there may be some fissuring of the top, weathered zone of these rocks, which may support some degree of water storage and flow.

Much of the bedrock is covered by Drift, dominantly Flandrian peat, which also appears to cover (and perhaps largely obscure) other underlying Devensian glacial deposits. Nonetheless, a number of areas of exposed Devensian material have been mapped by BGS, some on the Cross Lochs ridge but particularly (though by no means exclusively) as a swarm of deposits, mostly elongated roughly SW–NE, along the sides of the Ewe Burn valley (which drains much of the Cross Loch ridge eastwards to Halladale River). BGS mapping shows most of these deposits as undifferentiated Till and Morainic Deposits, but with some as 'Hummock (Moundy) Glacial Deposits', comprised of 'sand, gravel and boulders'. It is likely that similar material underlies some, perhaps much, of the area mapped as Peat, but the extent of this is not known. Such deposits are likely to be water-bearing, at least in part.

The ecohydrological properties of both bedrock and glacial deposits in the Cross Lochs area seem to be little known. Their possible importance to surface conditions in the peatland depends not only on their character, but on their configuration and continuity. Evidence for a localised input of telluric water into the two areas that have been designated as 'fen' was derived, in the first instance, from a recognition of their distinctive vegetation, but was subsequently substantiated by hydrochemical and other measurements (Wheeler & Shaw, 1989; Charman, 1990, 1993). The hydrochemical impact of these telluric sources may be disproportionately greater than their contribution to the water balance of the mire, though they are clearly important locally in this regard, in the areas of scalariform fen.

[1] Million years

8.5.2 Observed water sources

Most of the peatland at Cross Lochs is likely to be fed predominantly by direct precipitation input, giving rise to extensive development of ombrogenous peat. On sloping surfaces, there is likely to be significant endotelmic flow through this, probably mostly through near-surface ('acrotelm') layers, and in appropriate topographical locations this may become focussed along broad soakways.

At the North-east Fen (Cross Lochs B (see Section 8.4.2)), Charman (1995) suggested that the head of the mire valley is fed by a "diffuse flushed zone", which originates from a lochan a short distance to the south-east. He commented further that "There is no obvious spring like that found at Cross Lochs 'A', but there are other, more minor seepage zones along the base of the western slope. A series of swallow holes occurs at the foot of the patterned fen area, and further down the valley, this underground water course emerges as a small stream." At the East Fen (Cross Lochs A (see Section 8.4.1)) he had noted (Charman, 1994a) that "The present mire surface of Cross Lochs A slopes gently over most of its surface, with a steeper area at the head of the mire. A seepage spring occurs at the break in slope. Swallow holes to the north indicate a subsurface water flow, although this is probably derived from further away." Aerial imagery suggests that the northern patterned surface at East Fen is embedded within a narrow, and presumed shallow, apparent flow-track, that extends upslope well above the main patterned area.

8.5.3 Mire development and water conditions

In the early stages of mire development, before ombrotrophic surfaces were much established and peat development was mainly restricted to basins and hollows, it may be expected that over most of the eastern slope of the Cross Lochs ridge the wetter areas were irrigated by downslope flow of surface water run-off, and perhaps also by more localised groundwater outflow. Together, these telluric sources would have helped to maintain minerotrophic conditions in the developing mires in the small valleys. However, over most of the area, these were replaced subsequently by ombrogenous peat. This appears to have occurred by two different routes: in the hollows and basins, ombrogenous peat seems to have developed by terrestrialisation of the preceding fen; on the adjoining slopes, by paludification, starting probably at a variable, but generally somewhat later, date.

In his 'patterned fen' sites, Charman (1995) suggested three possible causes of the development of ombrogenous conditions upon the underlying minerotrophic peat at between about 6400 and 6000 BP: natural autogenic succession in an oceanic climate; climate change and increased surface wetness; and anthropogenic influences (burning). Of these, he discounted the likelihood of burning as a generic forcing factor, as at "Cross Lochs B the transition had undoubtedly begun well before the occurrence of abundant charcoal, so burning cannot be the sole cause". Two additional possible explanations can also be advanced. One is that the initiation of surface acidification in the hollows was associated not with an increasingly wet climate, but with climate *drying* and a reduction of minerotrophic inflows so that, away from the immediate proximity of telluric sources, the mire surface became increasingly ombrotrophic. Another is that podsolisation (leaching) and acidification of the adjoining mineral slopes may have led to a progressive lowering of base-status of telluric surface water supply. This last is less likely to provide a satisfactory explanation if the telluric water source was of deeper (groundwater) origin.

The eventual resurgence of minerotrophic conditions in the two patches of scalariform fen seems to date from around 2700 BP and appears to be coincident with the development in the ombrotrophic area of a "wetter *Sphagnum* community" and a recurrence-surface–like feature. This can be interpreted as a response to climatic change (increasingly wet and cool) and, in the areas of the patterned fens, the return of minerotrophic conditions could be because "the emergence of springs supplying groundwater at the head of suitable slopes led to the provision of adequate moisture and nutrients for the vegetation change" (Charman, 1995). However, there seems no reason to suppose that such springs did not already exist in the areas of the 'patterned fens' before, and even during, the 'ombrotrophic' phase of their development. During this period they were clearly of insufficient magnitude to constrain the widespread establishment and development of ombrotrophic conditions, but they may well have stopped it occurring everywhere.

Examination of Charman's stratigraphical sections suggests that there is no convincing evidence for ombrotrophic conditions at any time during mire development along the western-most edge of the North-east Fen (Cross Lochs B), where the peat is thin and where seepages are reported from the adjoining steepish hill slope (Charman, 1995). It is therefore consistent with his stratigraphical data to suggest that a soligenous minerotrophic fringe persisted along the western margin of the mire, as telluric influence became confined to the valley edge by the advance of ombrotrophication from the east. The subsequent replacement of ombrotrophic conditions by minerotrophy beneath the present patterned fen can thereby be interpreted as a resurgence of existing telluric water sources, resulting in their limited re-advance onto the western edge of the existing ombrotrophic surface. Such a proposition most likely implies a significant groundwater source, along the base of the western hillside, possibly derived from glacial material.

Interpretation of likely ontogenic sequences at the East Fen (Cross Lochs A) is less clear than at the North-east Fen (Cross Lochs B), possibly because the stratigraphical sections (especially the longitudinal section) cross a more variable sub-peat topography. However, there is little clear evidence for ombrotrophic peat in cores 9 and 10, which are situated in or near the two sub-peat valleys, and it seems reasonable to suggest that minerotrophic conditions may have persisted in these, interrupted perhaps by some phasic drying but not necessarily by ombrotrophication. These core locations are peripheral to the main zones of present-day water flow and surface patterning, as identified by Charman (1994a), but seem likely to be responsive to the same source of telluric water, which perhaps relates to the present-day spring identified by Charman. In the absence of further information on sub-peat conditions, any further comment can only be speculative, but it is tempting to suggest that both of the sub-peat valleyheads are cut back into water-bearing mineral ground, possibly of glacial origin, and that peripheral seepage around these may have helped to perpetuate minerotrophic conditions locally during the 'ombrotrophication phase', in a zone squeezed beneath the mounds and ridges of higher ground (which became ombtrotrophic by paludification) and the basins of deeper peat (which became ombrotrophic by terrestrialisation). Nonetheless, it is clear that, unlike the North-east Fen, the resurgence of minerotrophy after about 2700 BP, has not followed the (largely peat-infilled) sub-surface valleys, but may be a consequence of enhanced groundwater outflow from other locations at the base of the hillslope that rises quite steeply southwards from the fen.

The possible significance of groundwater outflows are emphasised here because these seem most likely to account for both the persistence and localisation of telluric conditions in the mire, not because this is known to be the case. The mapped presence of 'exposed' Neoproterozoic bedrock a short distance above both fen sites, and perhaps extending downslope beneath what may generally be shallow peat, point to a possible source of telluric enrichment. However, it is notable that similar circumstances apply equally, or more, to the large area of ombrotrophic mire that was also examined by Charman (1995), which suggests that this rock does not have a pervasive influence upon present surface conditions in that area. The absence of a reversion to minerotrophic conditions in the ombrotrophic area may perhaps imply that significant groundwater outflows were not present here and that any basal deposits of early fen peat were primarily a consequence of surface run-off from the flanking slopes of mineral ground.

8.5.4 Implications for mire characterisation and typology

As described by Charman (1995), his ombrotrophic mire area at Cross Lochs "is a patterned ombrotrophic mire with round to oval pools ('central watershed blanket bog' of Lindsay *et al*., 1988), sloping gently approximately south to north, with a flat area at the southern end." In fact, as he recognised, it is more complicated than that, with at least three distinctive components of ombrogenous mire, reflected in different types of vegetation. In addition to the "patterned ombrotrophic mire with [deep] round to oval pools", which is particularly associated with the "flat area at the southern end", there is also a particularly wet area, with much *Sphagnum* and numerous shallow pools, located over a (probable) late-glacial basin at the lower, northern end of the mire; there are also thin and drier peats, mostly on more strongly-sloping ground. These three components each have their own characteristics, and probably different hydrodynamics, and only the area of "patterned ombrotrophic mire with round to oval pools" conforms with the concept of "central watershed blanket bog", as described by Lindsay *et al.* (1988). This leaves open the question of how the other two units are supposed to be categorised and named. What is clear is that they are not specific to "central watershed blanket bog".

The two patches of scalariform fen have a very distinctive surface relief of narrow ridges and pools, aligned across the slope to give a ladder-like appearance. Lindsay *et al.* (1988) pointed out that they do not have a central watercourse which, in their view, distinguished them from a 'valley mire'. However, the same comment could be made for other sites in Britain that are routinely given the variable and ambiguous label of 'valley mire'. Partly to circumvent this, Wheeler *et al.* (2009) designated analogous systems, which might or might not have some axial water flow, as examples of 'percolation troughs', and any flow paths within them as either soakways or water tracks, depending on the exposure of open water at the surface. On this basis, the scalariform fens at Cross Lochs could be regarded as examples of 'percolation troughs' overall, dominated by minerotrophic water tracks. The scalariform surface pattern is not unique to these examples of percolation troughs in the north of Scotland, but can also be found elsewhere, in a rather different guise, including southern Britain (Daniels, 1985). In neither case is its causation known (the developmental model proposed by Lindsay *et al.* (1988) was premature, and is almost certainly incorrect (Charman, 1994a, 1995)). The examples in the Flow Country provide particularly striking surface 'ladders', but they are also variable; in some instances the ridges are base-rich and obviously minerotrophic; in others, they support acidophilic species and may possibly be ombrotrophic (Charman, 1993) (the pools are always minerotrophic). This variability, and the lack of understanding of the causes of 'ladder' formation, may argue against the recognition of scalariform surfaces as a distinctive type of mire, in their own right, in favour of a more generic assessment of mire type (such as 'percolation trough') upon which has been superimposed a distinctive surface ornamentation, caused by the differential growth of plants and vegetation.

8.6 References for the Flow Country

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9 Scottish Peat Surveys

9.1 Background

During the period 1949 to 1961 a series of surveys were made of peat deposits in Scotland for the Department of Agriculture & Fisheries for Scotland. Some 103,000 acres (around 41,700 ha) of peatland were surveyed, primarily for assessing their potential for 'development' (particularly peat extraction for fuel and agricultural conversion). The results were published in part by Department of Agriculture & Fisheries for Scotland (1964, 1965a,b, 1968). In these volumes a brief description is given of each site examined, the characteristics of its peat and (usually) a single, levelled peat section. They also relate the site to the system of peatland classification in use by them at the time (Fraser, 1948). The sites were all from lowland contexts, but they have direct relevance to the 'low-altitude uplands' in parts of Scotland and also help to inform the characteristics of 'upland' bogs elsewhere.

Department of Agriculture and Fisheries for Scotland (1964). *Scottish Peat Surveys. Volume 1 – South West Scotland.* HMSO, Edinburgh.

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The peat sections were recorded along a number of secondary transect lines aligned orthogonally to a base line. Peat depth was measured at intervals of about 100 m. The botanical composition, humification and other features were described at 50 cm intervals from peat cores collected at selected sampling points (the intervals of these coring points is not clear but appears to have been at least 100 m). A number of peat sections appear to be available from the sites examined, but only one, which was considered to be typical of the site as a whole, is (usually) presented in the published reports. It is presumed that unpublished material may still be available (at the former Macaulay Institute for Soil Research, Craigiebuckler), but only the published material has been considered here.

9.2 Selected sections

A number of sections are provided here (Figure 12), selected to show the range of topographical and stratigraphical variation amongst the Scottish peat deposits that had been surveyed. It is important to recognise that the individual sections may not necessarily well represent the overall 3D surface of the site in question, though they were considered to be 'typical'. The individual sections are not described or discussed here, but they are cross-referenced from the main text of this report where they help to illustrate specific points. Also, some summary details have been extracted from the reports for each of the sites, and these have been tabulated (Table 4).

Table 4. Summary details of peatland sites in Scotland for which stratigraphical profiles published by the Scottish Peat Survey are presented. Data have been sourced from Department of Agriculture and Fisheries for Scotland (1964, 1965a, 1965b, 1968).

The material presented here has been extracted and summarised from the reports listed above and is intended to reflect their original contents, names, categories and terms, not necessarily our concurrence with these. Exceptions to this (modifications or comments) are enclosed in square brackets, apart from values of MRD (mean annual number of rain days). These have been calculated from the values for the mean annual number of non-rain days that were presented in the reports. Sequence of sites is grouped roughly by their topographical characteristics.

Rainfall*: superscript indicates measurement station and period of measurement:

bl	Borrobol Lodge, Sutherland (1942–1950)	ns	Newton Stewart (1948–1957)
cl	Carluke, Lanarkshire (1946–1955)	st	Stornoway (1942–1951)
dm	Dumfries (1948–1957)	wk	Wick Airfield (1944–1955
kp	Kippen, Stirlingshire (1947–1956)		

MAR: Mean annual rainfall; MRD: Mean annual number of rain days.

Grid References were given by the authors to indicate the approximate centre of the sites.

Status: details taken from the Defra 'Magic' map (https://magic.defra.gov.uk/magicmap.aspx (accessed May 2020))

Peat: abbreviations are: C: *Calluna*; Cx: *Carex*; E: *Eriophorum*; P: *Pinus*; Ph: *Phragmites*; S: *Sphagnum*; T: *Trichophorum*; W: Wood

Mean peat depths and humification (H) ratings are as stated; reference to more than one depth or H value at a site reflects different values given for sub-sites, where these exist.

Geology: ORS: Old Red Sandstone

Peatland Classification: RB: Raised bog; RBB: Raised Basin Bog; BB: blanket bog. *NPRI*: Lindsay & Immirzi (1996)

Site	Peat characteristics	Geology	Peatland classification
Lochar Moss Dumfriesshire 7–17 m aOD. Rainfall[dm]: MAR: 108 cm; MRD: 200 d Site includes Craigs Moss NY015737 Racks Moss NY030725 Ironhirst Moss NY042712 Longbridge Moor NY047688 **Status:** Longbridge Muir is SSSI and SAC (Solway Mosses North), others are non-designated.	S forms bulk of peat, with variable but significant amounts of C and E, over a quite thick (mostly <1.5 m) layer of Cx, W and Ph and, in places, *Cladium*. Mean depths of virgin [uncut] peat: 3.8 m 4.8 m 5.0 m 5.0 m	Probably raised beach deposits (sands, gravels, clays) beneath most of mire, over glacial gravels and sands. ORS bedrock.	Raised Basin Bog(s) *NPRI*: Raised Bog (Nithsdale): Craigs Moss, Racks Moss, Longbridge Muir. (Ironhirst Moss: no entry.)
Moss of Cree Wigtownshire 8–14 m aOD Rainfall[ns]: MAR: 116.3 cm; MRD: 209 d NX 435605 **Status:** Galloway and Southern Ayrshire Biosphere Reserve	S is chief constituent, with E [mainly top half] and some C. Cx and W [mostly forming a thick (*c.* 2 m) basal layer of fen peat in section, but apparently not over most of site]	Raised beach deposits (clays) overlying boulder clay or bedrock (Silurian Greywackes)	"The bog is remarkable in the way in which it comes to a sudden stop at almost all points on its perimeter." Raised Basin Bog *NPRI*: Raised Bog
Flanders Moss East Stirlingshire 12.5–20.9 m aOD Rainfall[kp]: MAR: 128.5 cm; MRD: 208 d NS 635985 **Status**: NNR, SSSI, SAC (Flanders Mosses)	Two main peat layers: upper layer (*c.* 3 m) mainly S with some E and a trace of C; lower layer similar but much more C. Occasional Cx and W peat at base. Av depth: 4.3 m; most peat was H4–H5	Carse Clay	Raised Basin Bog *NPRI*: Raised Bog

Site	Peat characteristics	Geology	Peatland classification
Flanders Moss West Stirlingshire 14–20 m aOD Rainfall[kp]: MAR: 128.5 cm; MRD: 208 d NS560960 **Status**: Non-designated	Largely S–E peat, with more C at 3–4.5 m bgl. Thin basal Cx and W peat. Av depths: 3.4–4.6 m. Av H: H5–H6	Thick clay, similar to Carse Clay	Raised Basin Bog *NPRI*: Raised Bog
Gartur Bog Perthshire 15–30 m aOD Rainfall[kp]: MAR: 128.5 cm; MRD: 208 d NS 565984 **Status**: Non-designated	S forms bulk of peat, with some E and less C. [Basal fen peat, except on low ridges, with Cx and W.] Av. depth: 4.9 m; Av. H: H6	Part over hummock moraine [sandstone clasts], mostly over an alluvial clay of variable sand content. All over Lower ORS	Raised Basin Bog. Some thin peats [not on section] have BB characteristics. *NPRI*: no entry
Dergoals Moss Wigtownshire 73–121.9 m aOD Rainfall[ns]: MAR: 116.3 cm; MRD: 209 d NX 260610 **Status**: Galloway and Southern Ayrshire Biosphere Reserve	Irregular surface topography, with peat split by glacial material. S–E peat with basal Cx and W [fen peat, esp. in hollows] Av. depth(s): 2.4–7.1 Av. H: H6–H7	Bedrock formed of steeply dipping Silurian grits, greywackes and shales, which underlie much of the peat. In places boulder clay forms ridges (drumlins) that appear to determine the sub-surface topography in places.	Some topographical similarities with BB, but appears to comprise a number of raised bogs. Raised Basin Bogs have extended outwards in upper strata and joined to form a ± continuous cover *NPRI*: no entry.
Achnacree Moss Argyllshire 2–27 m aOD Rainfall[ob]: MAR: 156.9 cm; MRD: 228 d NM 918357 **Status**: Non-designated	Most of the peat is S with E and C as major additional species. Average depth: 1.9 m. 52% samples H5 or less, increasing with depth.	Raised beach deposits which rest, possibly with an intervening layer of morainic material, on an uneven surface of volcanic rocks of ORS age.	Difficult to classify, perhaps nearer the form of BB than RBB. Little doubt that parts were RBB at some period during its development. *NPRI*: Raised Bog
Cranley Moss Lanarkshire 205.5–215.6 m aOD Rainfall[cl]: MAR: 87.2 cm; MRD: 286 d NS 934476 **Status**: SSSI, SAC	Bulk of peat is S, with some E and C. W and Cx present [as basal fen peat]. Av depth: 3.6; Av H: H7	Stiff, stony boulder clay of unknown thickness over Calciferous Sandstone below S part of bog. N part (N of fault) on basaltic lavas of Calciferous Sandstone age.	Raised Basin Bog *NPRI* (Clydesdale): Raised Bog

Site	Peat characteristics	Geology	Peatland classification
Ryeflat Moss Lanarkshire 206–215 m aOD Rainfall[cl]: MAR: 87.2 cm; MRD: 286 d NS 953481 **Status**: Non-designated	S is main peat sp, followed by E, with some C. Basal layer includes Wood. Compact Cx peat, with some wood and *Menyanthes.* Av. depth: 5 m; Av. H: H6	Moundy sand + gravel deposits, in places boulder clay. Mostly underlain by basaltic lavas of Calciferous Sandstone age, flanked to N and S by Caliciferous Sandstone sediments	Raised Basin Bog *NPRI* (Clydesdale): Raised Bog
Annabaglish Moss Wigtownshire ?–93 m aOD Rainfall[ns]: MAR: 116.3 cm; MRD: 209 d NX 285560 **Status**: Galloway and Southern Ayrshire Biosphere Reserve	S with lesser amounts of E and C. Cx and W form a basal layer Av. depth: 3.9 m Av. H: H6	Bedrock formed of steeply dipping Silurian grits, greywackes and shales, which underlie much of the peat. In places boulder clay forms ridges (drumlins) that appear to determine the sub-surface topography in places.	Group of Raised Basin Bogs. These have overtopped the basins in which peat formation started, resulting in the development of a continuous peat cover of variable thickness *NPRI*: no entry
Mindork Moss Wigtownshire Altitude not given; adjacent to above Rainfall[ns]: MAR: 116.3 cm; MRD: 209 d NX 312571 **Status**: Galloway and Southern Ayrshire Biosphere Reserve	Proportionately fairly thin layer of S peat with E and T, over a proportionately rather thick layer of Cx peat with some wood Av. depth: 3.5 m; Av. H: H6	As above	Extended period of Cx peat in places. Conformation is of a series of Raised Basin Bogs which have 'overflowed' their basins to form a continuous sheet. *NPRI*: no entry
Flow of Dergoals Wigtownshire ?–90 m aOD Rainfall[ns]: MAR: 116.3 cm; MRD: 209 d NX 248582 **Status**: SSSI, SAC, Galloway and Southern Ayrshire Biosphere Reserve	S is main peat former, with lesser amounts of E and C. Underlain by a quite thick (1–2 m) layer of fen peat with Cx and W, regarded as lacustrine deposits. Av. depths: 3.1–4.2 m; Av H: H6	As above	Raised Basin Bogs Has many features characteristic of BB but peat formation originated in shallow depressions under the influence of groundwater. Lens of Cx peat embedded in S thought to represent a former lochan. *NPRI*: no entry

Site	Peat characteristics	Geology	Peatland classification
Knock Moss Wigtownshire 82–99 m aOD Rainfall[ns]: MAR: 116.3 cm; MRD: 209 d NX 264572 **Status**: Galloway and Southern Ayrshire Biosphere Reserve (Scotland)	Much ± amorphous and indeterminate peat, but otherwise S most important, with some E and C. In hollows is underlain by Cx + W peat forming a layer up to *c.* 3 m and proportionately deeper than usual. Av depth: 3.0 m; Av H: H6	As above	Raised Basin Bog *NPRI*: no entry
Barvas Road Area Isle of Lewis [Altitude not given] Rainfall[st]: MAR: 108.47 cm; MRD: 243 d NB 410460 **Status**: Ramsar Site, SAC, SPA (Lewis Peatlands).	Mostly S–T peat with some C and E. Some Cx and W at or near the floor of the bog. Av depths: 2.2–2.4 m; Av Hs: H7, H8	Underlain by a variable Lewisian Gneiss, with an expected patchy cover of Drift, mostly a clastic tough sandy clay, locally a hummocky morainic material.	Blanket Bog – on the basis of conformation and the lack of marked stratification of the peat. *NPRI*: no entry
Achairn Bog Caithness 55–114 m aOD Rainfall[wk]: MAR: 78.05 cm; MRD: 227 d ND 265488 **Status**: Non-designated	Mainly S, secondarily T. Local E and some C. Locally basal W, with some C, mainly in hollows. Av depths: 2.0–3.3 m Av Hs: H7	Probably flaggy, micaceous sandstones and dark shales (ORS), probably with boulder clay beneath part of the site.	Little or no differentiation into distinct strata above [localised] basal layer with W, C and mineral material. Blanket Bog *NPRI*: no entry
Badanloch Bog Sutherland 101–192 m aOD Rainfall[bl]: MAR: 79.06 cm; MRD: 209 d NC 830300 **Status**: Non-designated	S–T peat, with some M, C and E. Layer of P *c*. 1 m bgl and B *c*. 1 m above floor of bog. Local basal Cx in some hollows. Av. depths: 1.9–2.2 m Av Hs: H7	Mica-schist heavily invaded by granitic veins. Around site, covered by a thick drift, a friable boulder clay with a somewhat loose sandy matrix and bedrock clasts: may underlie much of the peat	No distinct stratification except locally where there is basal Cx peat. [What about woody layers?] Blanket Bog *NPRI*: no entry

Site	Peat characteristics	Geology	Peatland classification
Loch nan Clar Bog Sutherland 121–190 m aOD Rainfall[bl]: MAR: 79.06 cm; MRD: 209 NC 755375 **Status**: Non-designated	S–T peat, with some C, M and Ea. Hard stratum of P *c.* 1.0–1.5 bgl. Occasional patches of Cx, Ph and W at bottom. Av depth: 2.2 m H variable – most often H6 to 1 m bgl, H8 below this.	Mica-schist heavily invaded by granitic veins. Around site, covered by a thick drift, a friable boulder clay with a somewhat loose sandy matrix and bedrock clasts: may underlie much of the peat	By conformation and situation classed as Blanket Bog with local development of Basin peat *NPRI*: no entry

Figure 12. Selected Scottish Peat Survey sections.

A number of sections are provided in the following pages, selected to show the range of topographical and stratigraphical variation amongst the Scottish peat deposits that were surveyed. They have been reproduced from the following documents:

Department of Agriculture and Fisheries for Scotland (1964). *Scottish Peat Surveys. Volume 1 – South West Scotland.* HMSO, Edinburgh.

Department of Agriculture and Fisheries for Scotland (1965a). *Scottish Peat Surveys. Volume 2 – Western Highlands and Islands.* HMSO, Edinburgh.

Department of Agriculture and Fisheries for Scotland (1965b). *Scottish Peat Surveys. Volume 3 – Central Scotland.* HMSO, Edinburgh.

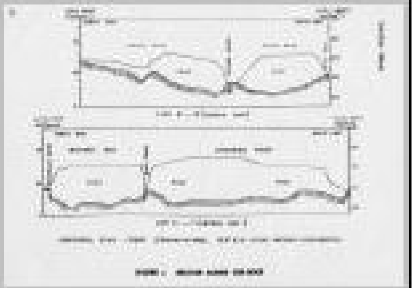
Department of Agriculture and Fisheries for Scotland (1968). *Scottish Peat Surveys. Volume 4 – Caithness, Shetland and Orkney.* HMSO, Edinburgh.

Fraser, G.K. (1948). *Peat Deposits of Scotland. Part I. General Account.* Geological Survey of Great Britain: Scotland. Wartime Pamphlet No. 36. HMSO, Edinburgh.

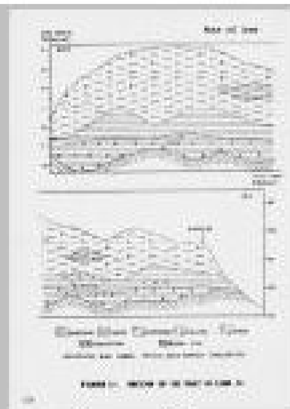
List of Sites

The sequence of sites is grouped roughly by their topographical characteristics (see Table 4), from 'Raised Basin Bog' to 'Blanket Bog' (Scottish Peat Survey nomenclature).

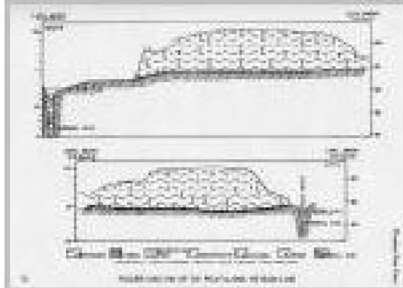
Lochar Moss, Dumfriesshire
Moss of Cree, Wigtownshire
Flanders Moss East, Stirlingshire
Flanders Moss West, Stirlingshire
Gartur Bog, Perthshire
Dergoals Moss, Wigtownshire
Achnacree Moss, Argyllshire
Cranley Moss, Lanarkshire
Ryeflat Moss, Lanarkshire
Annabaglish Moss, Wigtownshire
Mindork Moss, Wigtownshire
Flow of Dergoals, Wigtownshire
Knock Moss, Wigtownshire
Barvas Road Area, Isle of Lewis
Achairn Bog, Caithness
Badanloch Bog, Sutherland
Loch nan Clar Bog, Sutherland



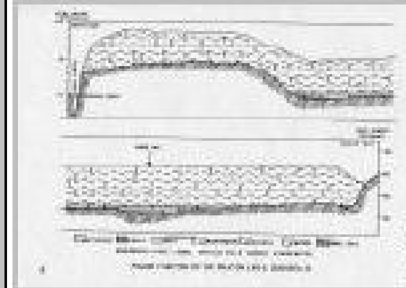
Lochar Moss



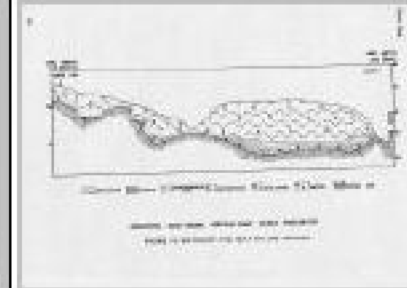
Moss of Cree



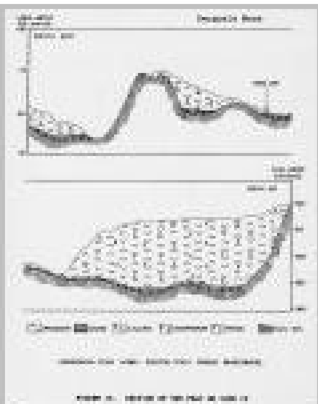
Flanders Moss East



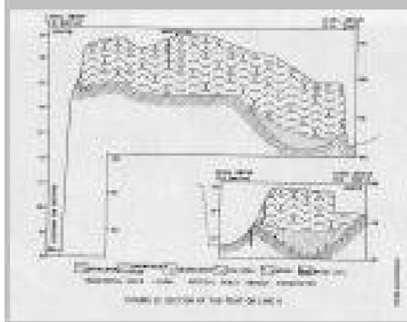
Flanders Moss West



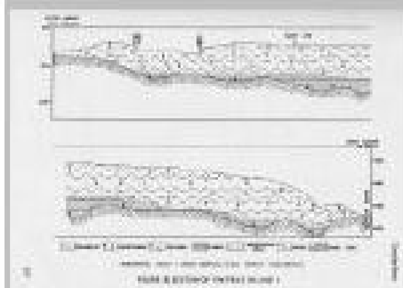
Gartur Bog



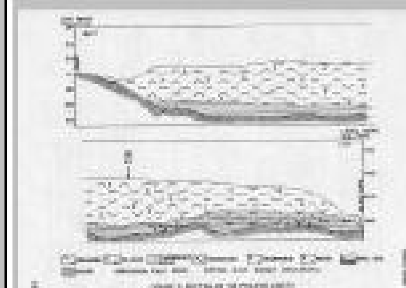
Dergoals Moss



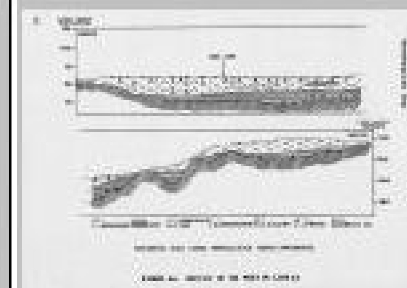
Achnacree Moss



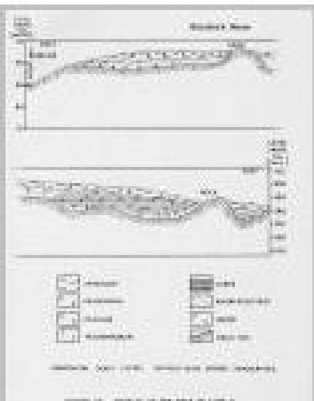
Cranley Moss



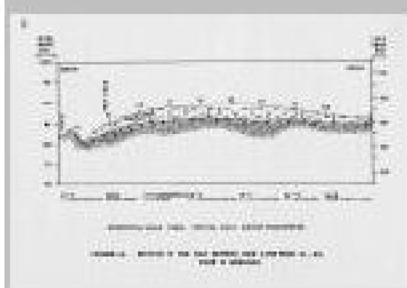
Ryeflat Moss



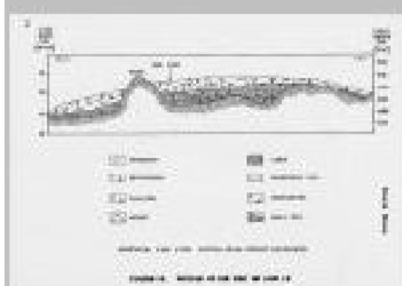
Annabaglish Moss



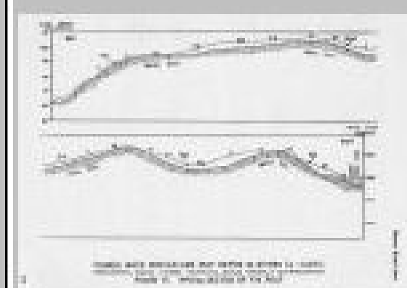
Mindork Moss



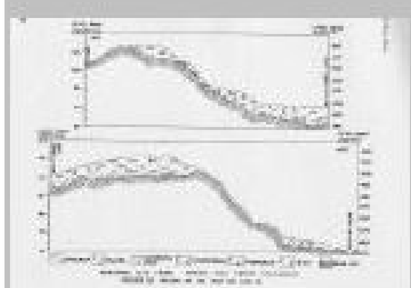
Flow of Dergoals



Knock Moss

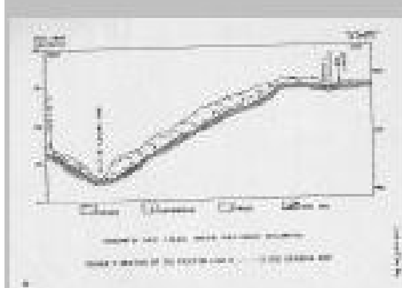


Barvas Road Area

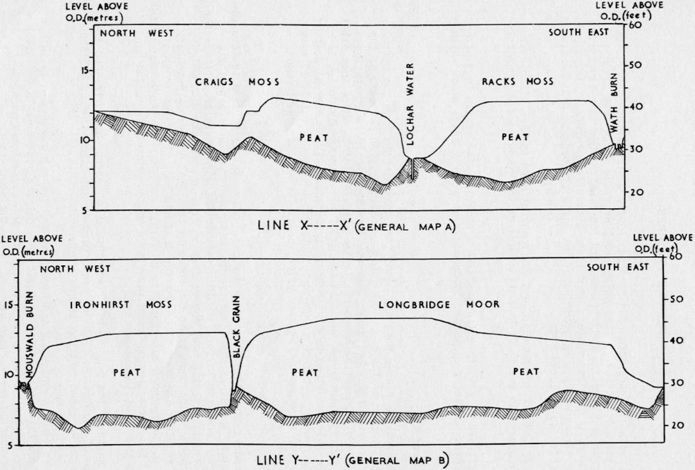


Achairn Bog

Badanloch Bog



Loch nan Clar Bog



HORIZONTAL SCALE 1:25,000. (2½ inches to 1 Mile). VERTICAL SCALE GROSSLY EXAGGERATED.

FIGURE 1. SECTION ACROSS THE BOGS

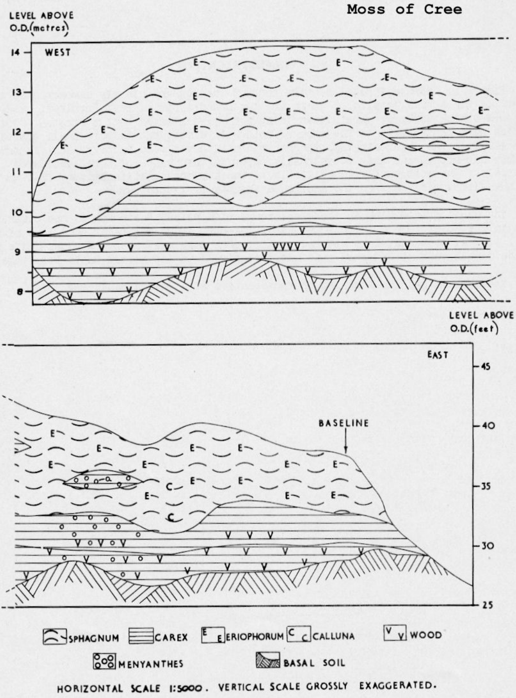
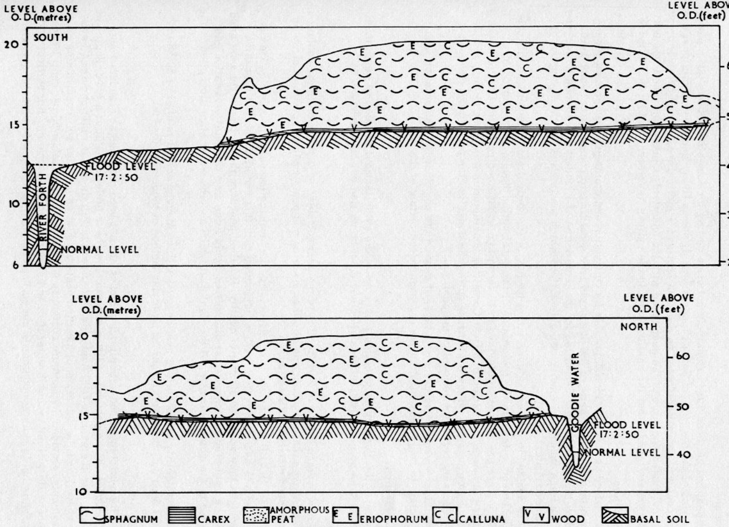
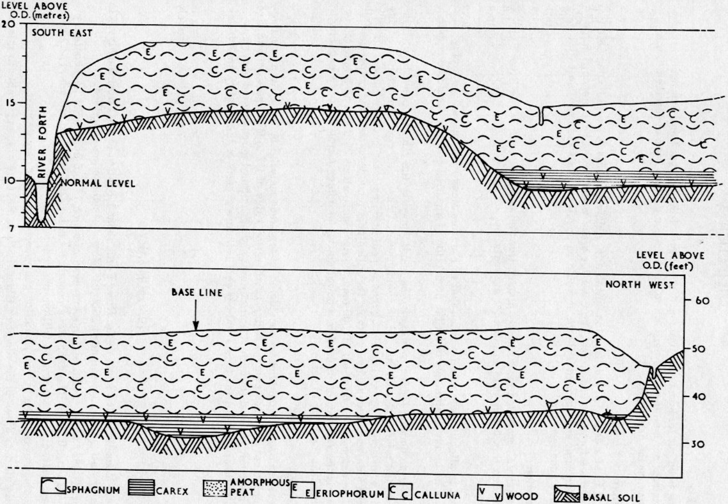


FIGURE 21. SECTION OF THE PEAT ON LINE 13



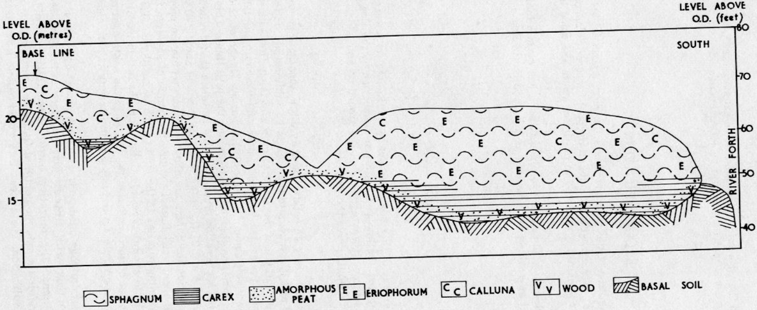
HORIZONTAL SCALE 1:10000. VERTICAL SCALE GROSSLY EXAGGERATED.

FIGURE 2 SECTION OF THE PEAT ALONG THE BASE LINE



HORIZONTAL SCALE 1: 5000 VERTICAL SCALE GROSSLY EXAGGERATED

FIGURE 7 SECTION OF THE PEAT ON LINE 6. SUB-AREA III



HORIZONTAL SCALE 1:5000. VERTICAL SCALE GROSSLY EXAGGERATED.

FIGURE 12. SECTION OF THE PEAT ON LINE 15 SOUTH

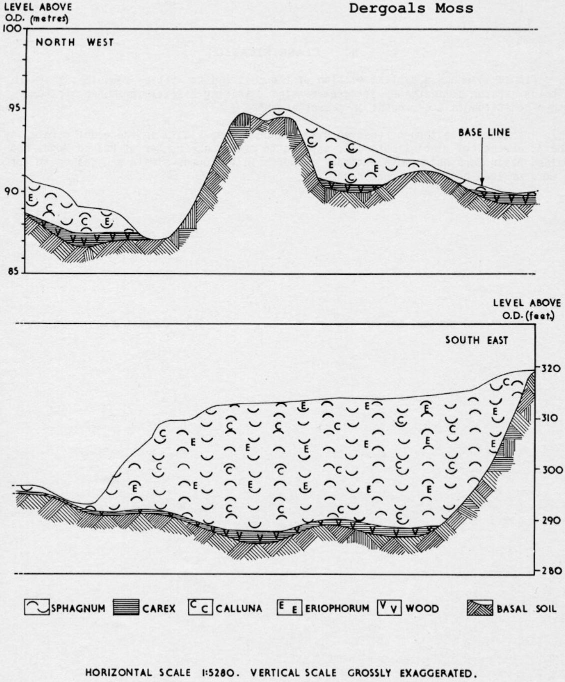


FIGURE 14. SECTION OF THE PEAT ON LINE 13

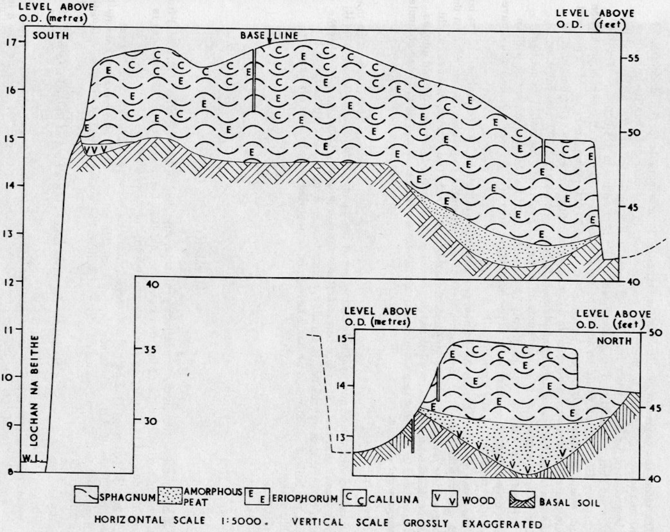
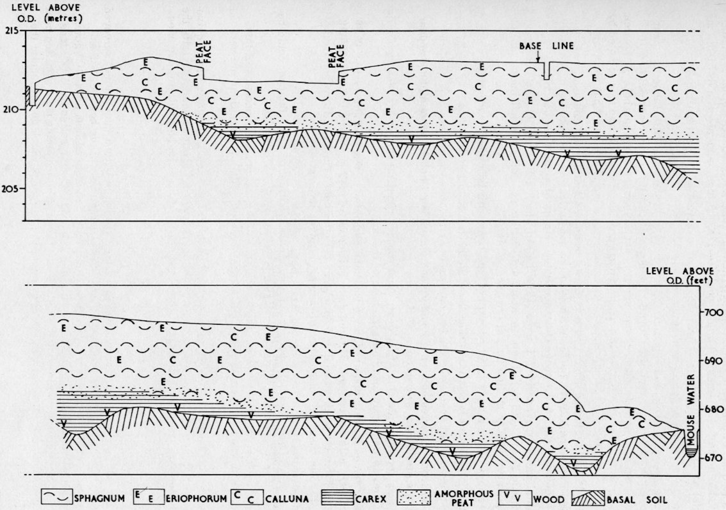


FIGURE 32. SECTION OF THE PEAT ON LINE 14



HORIZONTAL SCALE 1: 2500. VERTICAL SCALE GROSSLY EXAGGERATED.

FIGURE 30. SECTION OF THE PEAT ON LINE II

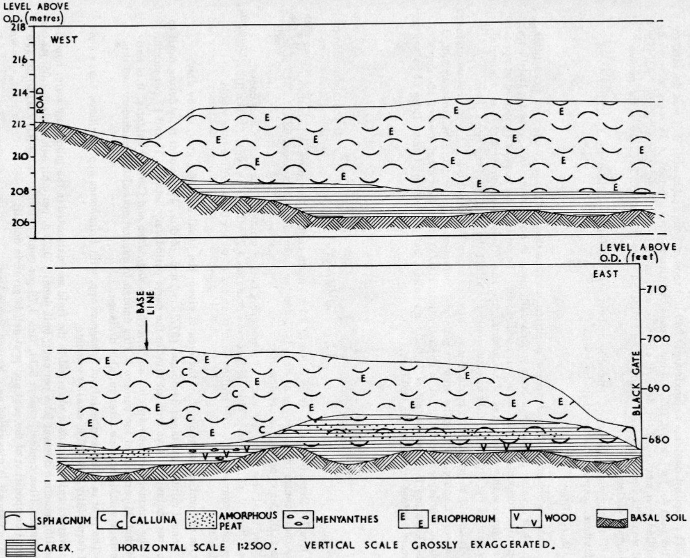
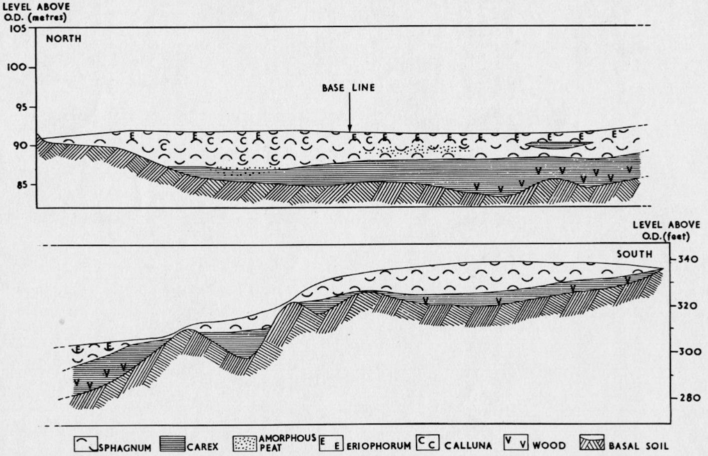


FIGURE 28. SECTION OF THE PEAT ON LINE 15



HORIZONTAL SCALE 1:5280. VERTICAL SCALE GROSSLY EXAGGERATED.

FIGURE 36. SECTION OF THE PEAT ON LINE 22

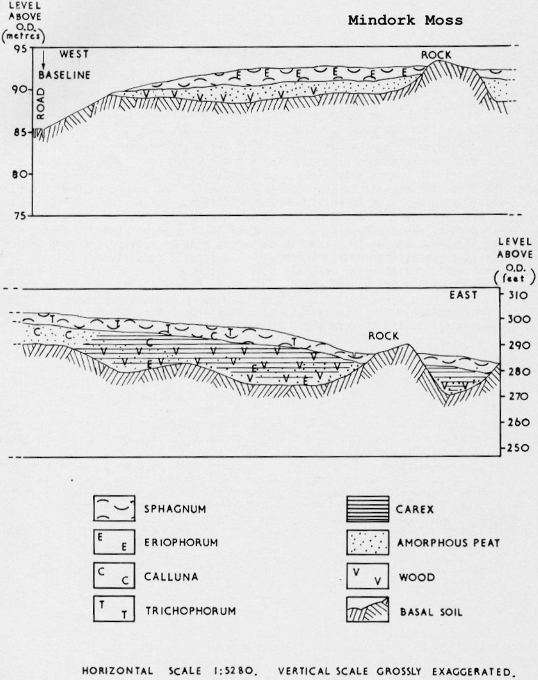
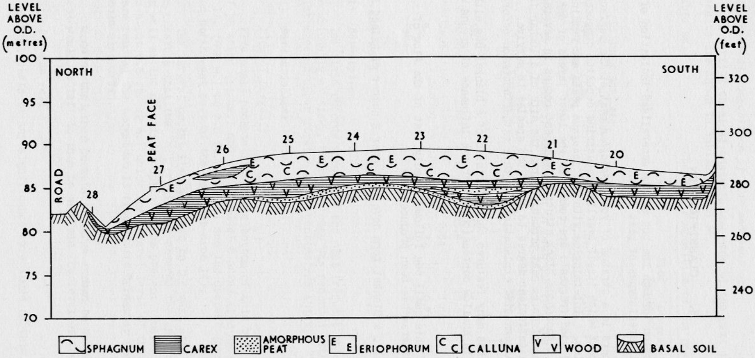
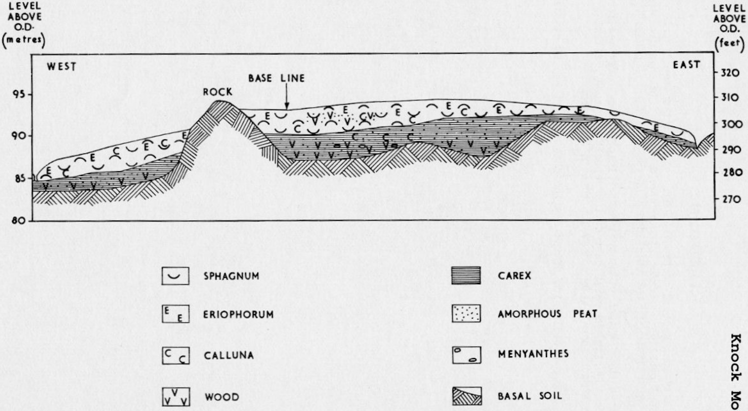


FIGURE 25. SECTION OF THE PEAT ON LINE 2



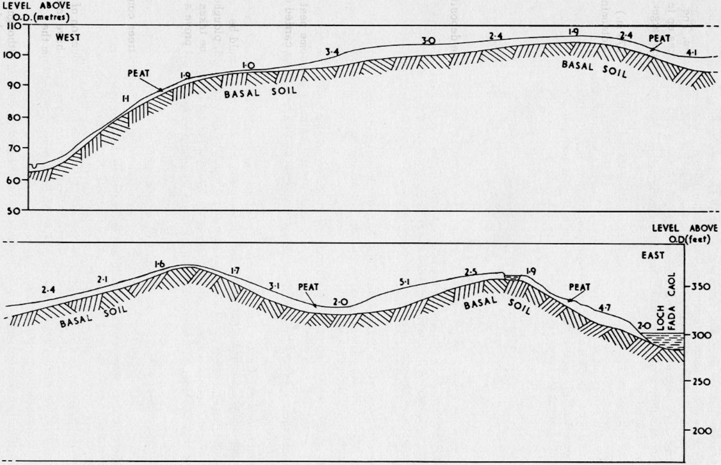
HORIZONTAL SCALE 1:5280. VERTICAL SCALE GROSSLY EXAGGERATED.

FIGURE 31. SECTION OF THE PEAT BETWEEN BASE LINE PEGS 20 - 28. FLOW OF DERGOALS

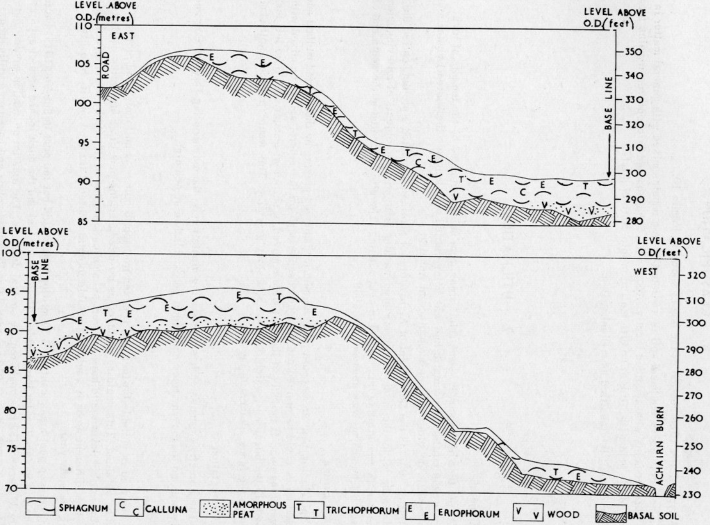


HORIZONTAL SCALE 1:5280. VERTICAL SCALE GROSSLY EXAGGERATED.

FIGURE 23. SECTION OF THE PEAT ON LINE 10



FIGURES ABOVE PROFILES ARE PEAT DEPTHS IN METRES (1m = 3.28 ft.)
HORIZONTAL SCALE 1:10560. VERTICAL SCALE GROSSLY EXAGGERATED
FIGURE 17. TYPICAL SECTION OF THE PEAT



HORIZONTAL SCALE 1:10560. VERTICAL SCALE GROSSLY EXAGGERATED.

FIGURE 10. SECTION OF THE PEAT ON LINE 15.

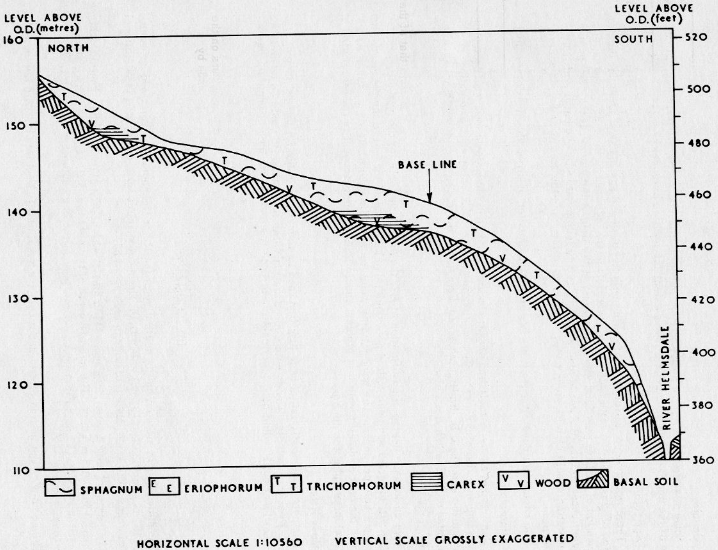
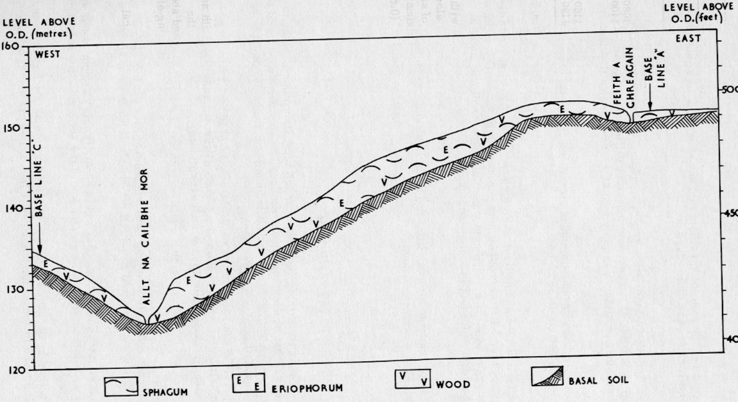


FIGURE 5. SECTION OF THE PEAT ON LINE 16.



HORIZONTAL SCALE 1:10,560. VERTICAL SCALE GROSSLY EXAGGERATED.

FIGURE 7. SECTION OF THE PEAT ON LINE X------X (SEE GENERAL MAP)

Working towards the development of Eco-hydrological Guidelines for Blanket Bog and Associated Habitat – A Scoping Study

Project code: ENV6003515

Annexe 2: Classification of upland peat soils

August 2020

Bryan Wheeler, Phil Eades, Ros Tratt & Sue Shaw

Sheffield Wetland Ecologists

Report to:

Environment Agency,
in partnership with Natural England, Natural Resources Wales, Scottish Environment Protection Agency and Scottish Natural Heritage

Contents

TABLES

1 Soil Survey of England & Wales

The following information has been compiled from details found in the legend to the 1:250,000 soil maps, the Soil Survey of England and Wales regional accounts (1984: Findlay *et al* (South West England); Hodge *et al* (Eastern England); Jarvis *et al* (Northern England); Ragg *et al* (Mid and Western England); Rudeforth *et al* (Wales)), Clayden & Hollis (1984), Burton & Hodgson (1987) and Avery (1990).

In soil classification, the elements classified are soil profiles, considered as 3-dimensional samples about 1 m^2 in cross-section, which extend from the ground surface (or a buried surface within 30 cm) to a maximum depth of 1.5 m. Classes are differentiated by characteristics that can largely be evaluated in the field. The system is hierarchical, with classes termed major soil groups, soil groups, soil subgroups and soil series defined at four successive categorical levels.

Peat soils are dominantly organic soils derived mostly from plant remains accumulated under wet conditions, either as autochthonous peat in the position of growth or as constituents of sedimentary deposits such as organic lake muds. Under the definition used by the Soil Survey of England and Wales they must have at least 40 cm of organic material[1] within the upper 80 cm, or at least 30 cm if it rests directly on bedrock and no overlying mineral layer that is more than 30 cm thick and has a non-humose B or C horizon at its base.

The soils are first divided into two main groups. 10.1: "Raw peat soils" – peat soils 'proper' that are undrained organic soils that have remained wet to within 20 cm of the surface since their formation; and 10.2: "Earthy peat soils" – in which drainage, with or without other man-induced changes, have led to the formation of a fully ripened and humified earthy topsoil.

Subgroups are differentiated by the dominant degree of decomposition (fibrous, semi-fibrous or humified) and pH within an arbitrary reference section that extends from 30 to 90 cm below the surface where the organic layer is more than 90 cm thick and starts nearer the surface where it is thinner.

The units that are mapped normally comprise more than one class, and usually take the name of the dominant class when the adjacent classes are similar or occupy a limited (< 15%) proportionate area (Avery, 1990). Units that include significant proportions of dissimilar kinds of soil, or in which no single profile class dominates, are termed compound and identified by the names of two or more constituent classes, by the additional terms *complex* or *association* or both. There are over 700 soil series now defined in England & Wales, of which over 400 are listed as major or minor components of soil associations in the legend of the 1:250,000 map (Avery, 1990).

Thus, some soil series are not shown on the soil maps as they do not cover significant, mappable areas. The Floriston series is a good example of this – it is not mapped as a separate unit, but examination of the accompanying texts shows that it can be an important component soil of the Winter Hill and Longmoss Associations among others (see below). Thus, for example, Walton Moss (Cumbria) is mapped as Winter Hill Association, but is considered to be 60% Floriston (Burton & Hodgson, 1987).

[1] Organic material is defined as comprising more than 12 or 18 percent organic carbon, dependent on the clay content (Avery, 1980).

1.1 Main soil associations and series on peat

1.1.1 Soil Associations

The following forms a brief outline account of the main types of peat soils identified by the Soil Survey of England and Wales, particularly in relation to those associated with ombrogenous systems.

The two main groups that are distinguished, (raw peat soils and earthy peat soils) are further subdivided into *Oligo*- (moist pH <4.0); *Eutro*- or *Eu*- (pH >4.0 in some part); *-fibrous* (mainly fibrous or semi-fibrous); *-amorphous* (mainly humified) and *sulphuric* (sulphuric subsoil within 80cm depth) subgroups. Here attention is restricted to the more oligotrophic examples.

10.1 Raw peat soils are undrained organic soils that have remained wet to within 20 cm of the surface since their formation, and thus do not have an earthy topsoil or ripened mineral surface layer.

10.11 Raw oligo-fibrous peat soils.

Longmoss:	Reference section *Sphagnum* peat
Winter Hill:	Reference section mixed *Eriophorum* & *Sphagnum* peat
Floriston:	Reference section grass–sedge peat.

10.13 Raw oligo-amorphous peat soils.

Crowdy:	Reference section humified peat.
Hepste:	Humified peat over lithoskeletal material (not mapped at 1:250,000)

10.2 Earthy peat soils are organic soils, normally drained, with a well aerated and structured, relatively firm surface horizon containing few or no recognizable plant remains.

10.21 Earthy oligo-fibrous peat soils.

Westhay:	Reference section *Sphagnum* peat
Turbary Moor:	Reference section mixed *Eriophorum* & *Sphagnum* peat
Ridley:	Reference section grass–sedge peat

1.1.2 Soil Series

The main soil series that occur in ombrogenous sites are described below. The descriptions and areas are taken from the legend to the 1:250,000 soil map, and details mainly from Burton & Hodgson (1987) and the Soil Survey regional accounts (Findlay *et al.,* 1984 (South West England); Jarvis *et al.*, 1984 (Northern England); Ragg *et al.*, 1984 (Midland and Western England); Rudeforth *et al.,* 1984 (Wales).

Longmoss (1011a)

Raw, oligo-fibrous peat soil, with reference section *Sphagnum* peat.

"**Raised bog peat**". Thick, very acid peat soils. Largely undrained and perennially wet. Many areas cut over or partly burnt.

Lowland bog and wet moorland habitats of low grazing value, some coniferous woodland; peat extraction.

Area: 226 km^2 (0.14%).

This series is considered to represent the final stage in development of raised bog peat and is often very deep. When reclaimed and cultivated the surface layers are rapidly decomposed to a black earthy state and the soils become the Westhay series (1021a).

The series mainly occurs in the lowlands of Cumbria, Lancashire, Staffordshire and South Yorkshire, and in small areas of North Wales. However, it is not confined to raised bogs, being also associated with blanket peat (*e.g.* on the Pennines) and flushes (e.g on Skiddaw) or springs (*e.g.* in south-west England, where the series forms part of the Hense Association). On higher ground on the Cumbria / Northumberland border it may be found where the peat extends upwards and outwards from the original basins to form a type of blanket bog.

The Longmoss Association has no ancillary subgroups or soil series listed in the legend to the Soil Survey of England and Wales map. However, the Longmoss series is given as an ancillary group under the Hense (871b) and Turbary Moor (1021) Associations.

In northern England the Longmoss series is the only important soil of the Longmoss association (map unit), which also includes Floriston, Wilcocks and Kielder. The latter two occur where the peat is less than 40 cm thick, and mainly on sloping ground. Floriston series occurs in former basin peat where the upper layers, derived from *Sphagnum* and cotton-grass, have been removed. Sites mapped as Longmoss Association include Bowness Common[1], Wedholme Flow, Glasson Moss and Solway Moss in Cumbria, Butterburn Flow (Cumbria/Northumberland), Thorne & Hatfield[2] Moors (South Yorkshire), parts of Spadeadam Forest (Cumbria) and Wark Forest (Northumberland).

In Midland and Western England the Association occupies about 13 km^2 of raised bog in Lancashire (at Chat Moss) and Staffordshire (*e.g.* Winmarleigh and Chartley Moss). Floriston, Altcar and Turbary Moor are component soil series, the former after removal of the upper layers of peat within a basin, and the latter two after cultivation of the raw peat.

In South-West England the Longmoss series occurs within the Hense Association, particularly on north- and west-facing slopes where springs are most frequent and have the strongest flow. It may also be included within the Turbary Moor Association where cutting has never taken place or was shallow, as on the Somerset levels.

The series apparently does not occur in eastern England, but occurs in small areas in North Wales, in hillside flushes within the Skiddaw Association (311b).

Winter Hill (1011)

Raw, oligo-fibrous peat soil, with reference section mixed *Eriophorum* & *Sphagnum* peat.

"Blanket peat". Thick, very acid raw peat soils. Perennially wet. Hagged and eroded in places.

Wet moorland and wetland habitats of poor grazing value; coniferous forest; military use.

Area: 2,575 km^2 (1.70%)

The Winter Hill Association is very extensive on the Pennines and common in Northumberland, Dartmoor and the Lake District. It also occurs on the North York Moors, Bodmin Moor and Exmoor. The peat is usually between 2 and 4 m thick, but is susceptible to erosion.

The Winter Hill map unit has no ancillary subgroups or soil series listed in the legend to the Soil Survey of England and Wales map. However, it is listed as an ancillary group under Revidge (311a), Skiddaw (311b), Bangor (311e), Wilcocks 2 (721d) and Crowdy 2 (1013b).

In Northern, Midland and Western England, the Winter Hill series is predominant within the Association, but Floriston and Longmoss are found in hollows, and Crowdy where the vegetation is

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[1] although 'Floriston predominates overall' (Burton & Hodgson (1987, p39)

[2] Thorne and Hatfield are mapped as Longmoss, although Burton & Hodgson consider the predominant soil at Thorne to be Floriston series, especially in the central portion of the mire, with some Winter Hill and Longmoss soils on the north and south margins. The predominant soil at Hatfield is the Winter Hill series with some Longmoss and Floriston.

dominated by *Molinia*. The Hepste series is also a component soil series found where amorphous peat lies over bedrock within 80cm. Both Bolton and Walton Mosses (Cumbria) are mapped as this Association, together with much of the blanket peats on the Pennine hills and including the Forest of Bowland and Bleaklow. The series is found as a component of raised bog soils at such sites as Prestwick Carr (Northumberland), Meathop Moss (Cumbria), Thorne & Hatfield Moors (South Yorkshire).

In South West England the Association occurs on Dartmoor and Exmoor (blanket bog on plateaux, cols & summits). The association includes Crowdy where humified, but conversely, the Winter Hill series occurs within the Crowdy 2 Association on Dartmoor in waterlogged hillside flushes and basins.

Not found in the east.

In Wales, Winter Hill is not mapped as an Association, but is found as a component of several Associations, *e.g.* Bangor (on gentle slopes), Brickfield 1 (basins), Crowdy 1, Crowdy 2 (chief associate), Hafren.

Floriston (1011)

These are raw oligo-fibrous peat soils formed in grass–sedge peat within oligotrophic basins in the uplands and lowlands. The Floriston soil series is not mapped as a unit, or referred to as an ancillary type, despite occurring as a common component of both the Winter Hill and Longmoss Associations.

In Northern England Floriston soils occur as a component within the following map units:

Clifton Association (711n) (in wet hollows on the Solway plain)
Hafren association (654a) (peat soils in basins, valleys or flushes).
Longmoss (1011a) (see above)
Onecote Association (721b) (in narrow valley floors)
Winter Hill Association (1011b) (in hollows).

In the Midlands and Western England it forms a component of Winter Hill Association, and Longmoss Association, while in south west England and in Wales it occurs as a component of the Crowdy 2 Association.

Most of the raised bog sites in Cumbria have Floriston soils as a component, and it predominates at Walton Moss (60%) and Bowness Common (Cumbria) and on Thorne Moors (South Yorkshire).

Crowdy (1013)

Raw, oligo-amorphous peat soils, with a reference section of humified peat. Crowdy is divided into Crowdy 1 and 2 Associations, and is listed as an ancillary series under Revidge (311a), Bangor (311e), Wilcocks 2 (721d), Wenallt (721e), Isleham 1 (861a), Laployd (871a).

Crowdy 1 (1013a). “Blanket and basin peat”.

Thick very acid amorphous raw peat soils. Perennially wet. Hagged and eroded in places. Some slowly permeable loamy soils with wet peaty surface horizons.

Wet moorland and wetland habitats of poor and moderate grazing value.

Area: 241 km^2 (0.15%).

The Crowdy 1 Association covers 240 km^2 on plateaux, gentle slopes and basins in the uplands of mid and north Wales. It includes some Winter Hill, Hafren & Wilcocks, among others. As well as the blanket peat, there are a few raised bogs (*e.g.* Gors Lwyd, Powys).

Crowdy 2 (1013b). “Blanket and basin peat”.

Thick very acid amorphous raw peat soils. Perennially wet. Hagged and eroded in places.

Wet moorland and wetland habitats of poor and moderate grazing value; military use.

Area: 589 km^2 (0.38%).

In Northern England, Crowdy is not mapped as an Association (and not divided into 1 and 2), but occurs as a component soil series of the Bangor and Wilcocks 2 Associations, where the peat thickens within these soil types.

In the west and south west of England and Wales, Crowdy 2 is mapped as an Association, where it comprises raw acid peat soils, occupying wide upland tracts of blanket bog and scattered peat filled basins in Wales and South-West England. A small area on the Black Mountains extends into Herefordshire. The chief associate is the Winter Hill series where there are more visible *Eriophorum–Sphagnum* remains. It is extensive on blanket bogs of Dartmoor with smaller patches on Exmoor and in the valley bogs of Bodmin Moor. Winter Hill, Floriston, Wenallt, Laployd, Princetown, Wilcocks & Freni are all included as component soil series. The association also includes some grass–sedge peats of the Floriston series in valley bottoms.

In Ceredigion, both Cors Fochno (Borth Bog) and Cors Caron (Tregaron Bog) are mapped as Crowdy 2 Association. "These have floristic and pedological affinities with blanket bogs, the peat having both amorphous and semi-fibrous layers unlike the dominantly fibrous peats of raised bogs elsewhere" (Rudeforth et al, 1984).

Westhay (1021)

Earthy oligo-fibrous peat soils, with reference section *Sphagnum* peat.

The Westhay soil series is not mapped as an Association, but in northern, mid, west and south-west England it forms a small component soil series of the Turbary Moor Association (1021), particularly where moss-dominated peats have undergone modest drainage improvements and reclamation to grassland provides conditions in the surface layers conducive to the formation of an earthy topsoil. Raised bog sites having Westhay soils include Holcroft / Glazebrook Mosses (Cheshire), Carrington Moss (Greater Manchester), Fenns & Whixall Mosses (Clywd/West Midlands), Brue basin (Somerset).

Turbary Moor

Earthy oligo-fibrous peat soils with reference section mixed *Eriophorum* & *Sphagnum* peat.

'Raised bog peat'. Deep earthy peat soils. Groundwater usually controlled by ditches and pumps. Very acid with high groundwater levels where uncultivated. Risk of wind erosion.

Permanent grassland and deciduous woodland; peat extraction; wetland habitats in Somerset; cereals; sugar beet, potatoes and field vegetables in the Fens.

Area: 154 km^2.

The Turbary Moor soil series are mainly described from Somerset (*e.g.* Shapwick Heath) and Lancashire (*e.g.* Chat Moss), being found on lowland raised bogs, variously modified from their original condition by drainage, peat cutting and reclamation for agriculture. The Turbary Moor series is mainly found in sites where the upper layers of moss peat have been removed, and / or modified by drainage and reclamation for agriculture, leaving a peat composed mainly of the coarse remains of cotton-grass. However, it is also found in basin mires, particularly where these have developed a '*schwingmoor*'. The Westhay series is the main soil constituent of the Turbary Moor Complex in the Brue basin, where the peatland still retains some of the upper layers of moss

In Northern England, Turbary Moor is mapped as an Association, which includes a small amount of Longmoss and Westhay series. However, the regional account (Jarvis et al, 1984) notes only one small occurrence in northern England (Burton, Hale and Holme Mosses (Cumbria)), although Turbary Moor soils are found as a component in some northern raised bog sites, including Prestwick Carr (Northumberland), Over Wyre & Fylde lowlands (Lancashire).

In Midland, Western and South West England, the main constituent of the Association is Turbary Moor series (earthy oligo-fibrous peat soils, with an earthy topsoil formed in acid cotton-grass peat where moss remains are subordinate). Longmoss series is included where cutting has never taken place or was shallow. The Westhay series may also be included (see above).

In the south west, it is estimated that since soil surveys in 1955 & 1965, the raised bog peats have been so exploited that only about 10 km^2 remain. Includes Shapwick Heath (Somerset).

Ridley (1021)

Earthy oligo-fibrous peat soils developed in grass-sedge peat in basins and valleys that have supported poor-fen communities. Acid & semi-fibrous.

The soil series is not mapped or given as an ancillary type for any of the mapped soil Associations.

In Northern England, Ridley soils occur as a component of Adventurers' Association, and in the mid and west also within Altcar 2 Association, Crannymoor Association (631f) (*e.g.* in hollows in the Delamere Forest), Delamere Association (631b) (where thick peat has accumulated in wet hollows), Downholland 2 Association (851b) (particularly at the margins of marshes along the Mersey).

Raised bog sites with Ridley soils include Glasson Moss and Wedholme Flow in Cumbria and Chat Moss (Greater Manchester), usually at the cut-over ± reclaimed edges.

The series apparently does not occur in south western or eastern England.

1.2 REFERENCES FOR SOIL SURVEY OF ENGLAND AND WALES

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2 Soil Survey of Scotland

Under the Soil Survey of Scotland (1984)[1], peat soils are defined slightly more restrictively than in England and Wales (see Section 1) as organic soils containing more than 60% organic matter and more than 50 cm thick. Organic soils are considered to cover 7660 sq. km (9.94%) in Scotland. These are divided into 'basin and valley peats' (666 sq.km) and 'blanket peat' (6,994 sq.km), and further subdivided into eutrophic flushed peat (flushed by seepage waters rich in mineral plant nutrients), mesotrophic flushed peat (flushed by seepage waters moderately rich in mineral plant nutrients), dystrophic flushed peat (flushed by seepage waters poorly supplied with mineral plant nutrients), and dystrophic peat (not affected by flushing), according to the influence of seepage water and nutrient status on the vegetation[2]. The Soil Survey of Scotland's scheme thus takes no account of the peat soil horizons, and is typological rather than definitional, depending more on the skill and experience of the surveyors (Soil Survey of Scotland, 1982). The areas given as peat soils are therefore an underestimate, as these soils occur as a component of many other map units.

About half of the information on which the mapping was based was derived from existing information (soil maps and unpublished surveys). The remainder (mostly in the Highlands and Southern Uplands) was done largely as a reconnaissance survey in which extensive use was made of air photograph interpretation techniques. The minimum size of a map unit for rounded shapes was taken as 75–100 ha, and for shapes longer than about 2 km, a minimum width of about 0.33 km.

The soil maps show the boundaries of 580 map units, only two of which show organic peat (although organic soils can form a component of other soil series). In contrast to the classification scheme used by the Soil Survey of England and Wales, the named associations are characterised by a particular combination of component major soil subgroups and land form (Avery, 1990). The soil association is a grouping of map units in which the soils are developed on similar parent materials (Soil Survey of Scotland, 1984). Thus, although peat soils are only identified in two, unnamed map units, they are known to occur as a component soil in many of the complex, or mixed, map units but the areas are too small to distinguish separately at the mapping scale (1:250,000) for which the minimum unit resolved is 75–100 ha.

As well as 'hill peat', areas mapped as "blanket peats" include some formations that originated in basins within the hills. Where peat on lowland terraces is contiguous with hill peats or extensive areas of organo-mineral soils, it is also mapped with blanket peats.

Basin & valley peat comprises those peat deposits which have formed under the influence of groundwater in confined or partially confined sites such as basins or river terraces. The peat usually shows some stratification in composition which reflects the changes in vegetation due to changes in hydrological conditions during the formation of the deposit. Thus, under the Scottish system, raised bogs are mainly included under the basin and valley peats since "a fully developed basin peat deposit has a convex or dome-shaped configuration" (and, interestingly are not referred to as raised bogs). They include sites such as Flanders Moss (Stirlingshire), Lochar Moss (Dumfriesshire), Moine Mhor, Claish Moss (Highland (Lochaber)), sites in the Moray Firth and on the Caithness plain.

Major revisions to the soil classification were made in October 2013, in which organic soils are now one of five divisions[3]. Different types of organic soils are distinguished under three of the 12 Major Soil Groups: Basin peats, Semi-confined peats, and Blanket peats – see Table 1.

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[1] Soil Survey of Scotland (1984). Organization and Methods of the 1:250,000 Soil Survey of Scotland. Macaulay Institute for Soil Research, Aberdeen.

[2] There seems to be no clear indication how these categories are recognised in the field.

[3] https://www.hutton.ac.uk/learning/soilshutton/soil-classification [Accessed 09-03-20]

Table 1. Descriptions of organic soils from the Scottish soil classification (2013).

Name	Simplified Description	Description
5 ORGANIC SOILS	Peat soils	Organic soils are formed under waterlogged conditions or where the natural decomposition rates of organic material are significantly slower than the rates of accumulation. These soils have more than 60% organic matter and exceed 50cm in thickness.
5.1 Basin peats	Poorly drained lowland peat soils with no mineral layer within 50 cm of the surface.	Major soil group: Basin peats. Basin peats develop in waterlogged conditions in topographic basins confined on all sides by mineral ground. The peat may develop in such a manner that it forms a dome shape whose peak is at a greater height than the edges; this is called a raised moss.
5.1.1 Eutrophic basin peat	Poorly drained, nutrient rich lowland peat soils with no mineral layer within 50 cm of the surface.	Eutrophic basin peat forms in topographic basins and is fed by waters that are rich in minerals. These peats support a wide range of plant species.
5.1.2 Mesotrophic basin peat	Poorly drained lowland peat soils with no mineral layer within 50 cm of the surface and moderately nutrient rich.	Mesotrophic basin peat forms in topographic basins and is fed by waters that are moderately rich in minerals. These peats usually supports a natural cover of plant communities with a high proportion of grasses and herbs.
5.1.3 Dystrophic basin peat	Poorly drained acidic and nutrient poor lowland peat soils with no mineral layer within 50 cm of the surface.	Dystrophic basin peat forms in topographic basins and is fed by waters that are poor in minerals. These peats usually supports vegetation communities dominated by heathers and nutrient-poor grasses. Where the bog has risen to the extent that the groundwater has little influence, the dominant vegetation community is heathland.
5.2 Semi-confined peats	Poorly drained partly confined peat soils with no mineral layer within 50 cm of the surface.	Major soil group: Semi-confined peats. Semi-confined peats develop in waterlogged conditions in valleys and terraces, between ridges, morainic mounds and drumlins and have at least one natural drainage outlet.
5.2.1 Eutrophic semi-confined peat	Poorly drained, partly confined, nutrient-rich peat soils with no mineral layer within 50 cm of the surface.	Eutrophic semi-confined peat is fed by waters that are rich in minerals and support a wide range of plant species.
5.2.2 Mesotrophic semi-confined peat	Poorly drained partly confined peat soils with no mineral layer within 50 cm of the surface and moderately nutrient rich.	Mesotrophic semi-confined peat is fed by waters that are moderately rich in minerals and usually supports a natural cover of plant communities with a high proportion of grasses and herbs.
5.2.3 Dystrophic semi-confined peat	Poorly drained partly confined, acidic and nutrient poor peat soils with no mineral layer within 50 cm of the surface.	Dystrophic semi-confined peat is fed by waters that are poor in minerals and usually supports vegetation communities dominated by heathers and nutrient-poor grasses.
5.3 Blanket peats	Poorly drained upland blanket peat soils with no mineral layer or rock with 50 cm of the surface.	Major soil group: Blanket peats are unconfined and 'blanket' the underlying topography. They form in wet, humid areas where there is an excess of rainfall over evaporation and where cool conditions inhibit the breakdown of organic material.

Name	Simplified Description	Description
5.3.1 Eutrophic blanket peat	Poorly drained, nutrient rich upland blanket peat soils with no mineral layer within 50 cm of the surface.	Eutrophic blanket peat occurs around spring lines that are rich in minerals and support a wide range of plant species.
5.3.2 Mesotrophic blanket peat	Poorly drained upland peat soils with no mineral layer within 50 cm of the surface and moderately nutrient rich.	Mesotrophic blanket peat occurs around spring lines that are moderately rich in minerals and usually supports a wide range of plant species with a high proportion of grasses and herbs.
5.3.3 Dystrophic blanket peat	Poorly drained, acid, nutrient poor upland blanket peat soils with no mineral layer within 50 cm of the surface.	Dystrophic blanket peat is largely rain-fed and mineral-poor and usually supports vegetation communities dominated by heathers and nutrient-poor grasses.