

## SOME OBSERVATIONS ON THE EROSION OF TARN MOSS BY THE WATERS OF MALHAM TARN

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### ABSTRACT

Tarn Moss, a raised bog at Malham Tarn, Yorkshire, was surveyed and the eroding cliff at the edge of the Tarn measured. The current outline of the cliff was compared with earlier maps and aerial photographs to estimate the rate of cliff erosion. A mean erosion (recession) rate of 7 cm a<sup>-1</sup> was obtained, corresponding to a peat loss of about 8 tonnes dry wt a<sup>-1</sup>. Studies of the Tarn sediments suggest that peat erosion only became significant after the damming of the Tarn in 1791 which raised the water level by ca 1.3 m. While there is evidence for surface erosion of blanket peat in the Pennines over the past 1000 years, data from Malham Tarn sediment cores show that erosion of the Moss only became significant after the damming event. Morphometric measurements of the peat rand of Tarn Moss suggest that the original peat margin could have extended up to 50 m beyond the present shoreline reducing the present area of the Tarn by as much as 10 ha. However, estimates obtained from the recession rate, lake sediments and evidence from early maps suggest that a total loss of 15-20 m of peat is more likely.

Key words: peat, cliff, erosion, raised bog, lake, sediment, dam.

### INTRODUCTION

TARN MOSS is the name given to the raised peat bog situated immediately to the west of Malham Tarn in North Yorkshire and is well known to visitors of Malham Tarn Field Centre. The Moss has been the focus of several detailed investigations. The broad history of the Moss was unravelled by Pigott & Pigott (1959) who took a series of peat cores for pollen analysis. Their study showed that the Moss began to form about 8000 years ago at the shallow end of a larger Tarn and grew to a greater extent than is apparent today. Other investigations have concentrated on the present flora and hydrology of the Moss and surrounding fen (Raistrick, 1947; Sinker, 1960; Proctor, 1974; Proctor, 1995; Cooper & Proctor, 1998).

This investigation concerns the erosion of Tarn Moss by the waters of Malham Tarn which has resulted in the formation of a peat cliff on the west shore of the Tarn, where periodically, large slices of peat fall into the water and are washed away. Although the phenomenon has been evident for many years, measurements of the rate of erosion have received little attention. An investigation of the Tarn sediments indicates that eroded peat entering the lake has altered the characteristics of the recent sediments. It is clearly desirable to gain some understanding of the rate of this process, both for the conservation of the Moss and of the Tarn, and to evaluate the cause of this erosion as it may affect other upland lakes.

### *Tarn Moss*

The moss currently occupies an area of 39 ha (Fig. 1) and consists of one large, somewhat indented area of raised bog adjacent to Malham Tarn plus a few smaller areas to the north

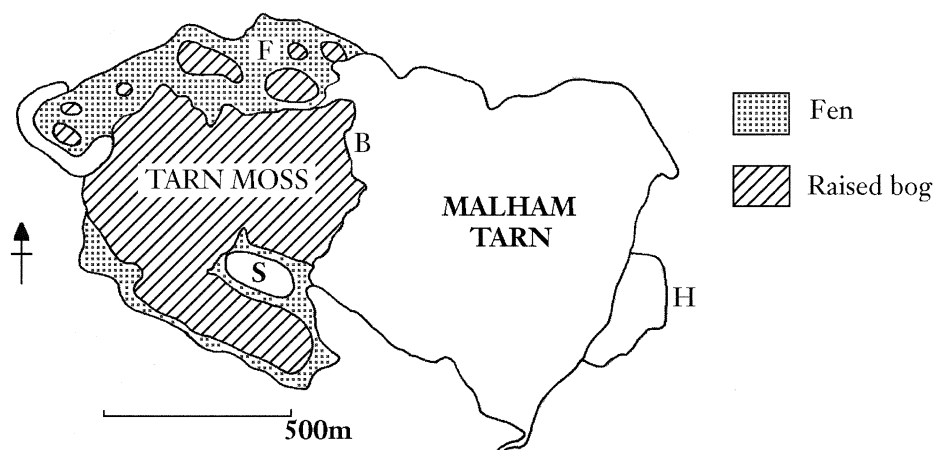


FIG. 1

Malham Tarn and Tarn Moss (re-drawn from Proctor, 1974).  
 B the 'bight'; F North Fen; H Ha Mire Plantation; S Spiggot Hill.

of Tarn Beck which are surrounded by fen. On its landward margin the Moss is girdled by a narrow 'lagg' consisting of a belt of mineral-rich soil supporting fen vegetation with a rich herb and sedge flora, while the Moss itself supports an acidophile flora with *Calluna vulgaris* (ling), *Eriophorum vaginatum* (cotton grass) and *Deschampsia flexuosa* (wavy hair grass). The Moss developed over a rough waterlogged terrain of kame and kettle moraine about 8000 years ago. Although much of the area was once occupied by the Tarn, some of the moraine must have originally formed low islands in the shallow water. The most prominent area of moraine is Spiggot Hill which rises well above the current level of the Moss and forms an isolated hill whose summit (388m) lies 14m above the present water level of Malham Tarn (Fig. 1).

The main Moss consists of two peat domes which rise to a maximum of about 5m above the level of the Tarn, separated by a natural soak running south to north into Tarn Beck (Fig. 2, profile b). The position of these domes may be controlled by the late glacial topography. Considerable areas of the Moss, particularly those bordering Tarn Beck and the soak have been cut for peat. The cuttings have eroded edges and appear to be of some antiquity but no historical records have yet come to light (Fig 2, profile a). The peat cliff which borders the Tarn runs south from the inflow of Tarn Beck. It begins as a low cliff about 1m in height which increases gradually to 2m as it enters the 'bight', the name given here to the large indentation in the cliff apparent in Figs 1 and 2. The indentation is about 75m in length and 30m deep and is underlain by a low moraine which the Moss has overgrown. Limestone boulders and cobbles of the moraine form the current shoreline for the Tarn in the centre of the bight and here, the peat cliff is reduced to about 1m in height above, and about 3m behind the present shore. The southern edge of the bight continues as a vertical or overhanging peat cliff falling directly into the Tarn and reaches its maximum height of 3.2 m. The cliff continues south around a promontory, maintaining a height of about 2.5 m until it descends once again into the small inlet below Spiggot Hill. Here it

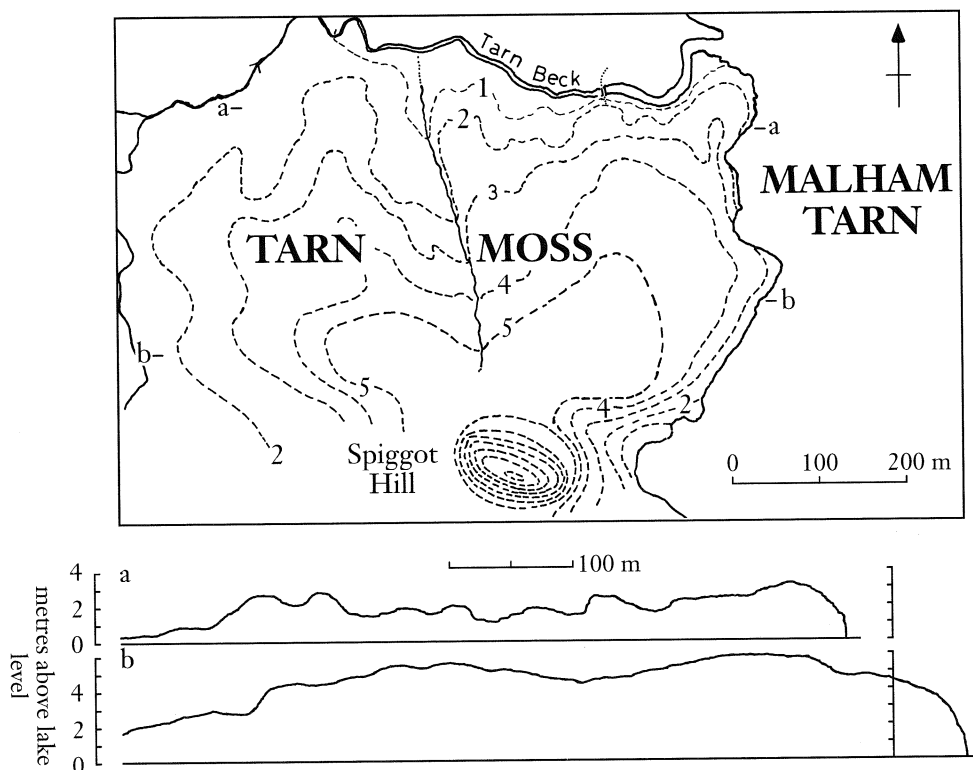


FIG. 2.

The topography of the main area of Tarn Moss, south of Tarn Beck.

Below, a) and b) show profiles across the Moss running approximately east west. a) is a profile about 50m south of Tarn Beck showing much evidence of peat cutting, b) is a profile near the promontory showing the two domes in an area where there has been little peat extraction.

Contours in metres above the Tarn water level

disappears, to be replaced by a low shore strewn with limestone cobbles. The total length of the peat cliff is about 430 m.

Cliff erosion is thought to have accelerated after the raising of the Tarn by approximately 1.3 m through the construction of a dam in 1791 by Thomas Lister (Holmes, 1965 p. 199). This may have been done to improve the fishing but the area of the Tarn was not greatly increased as a result. There remains some uncertainty regarding the impact of this event. Raistrick (1947 p. 164) mentioned that the water level was raised by a small embankment made when Mr. Morrison laid out the grounds of Tarn House. This must have been after 1852 when Morrison purchased the estate. The earliest maps of the outflow (Tarn Foot) show little detail of any of these works but significant alterations are evident between the late 18th C and the 1851/ 1852 map and also between that and the 1910 map. The embankment and the ironwork of the sluice gate appear to be Victorian but the possibility remains that these alterations were improvements which did not greatly alter the water level. However, the lower areas of the Moss and associated fen to the north of Tarn Beck were partially flooded by the rise in level of the calcareous waters of the Tarn leading to changes in the flora (Proctor, 1974).

Little is known of the recent history of Tarn Moss. Prior to 1955, the Moss was used for sheep grazing and grouse rearing (Sinker, 1960; A. Clunas, *pers. comm.*). A series of ditches, some of which appear to date from the 18th century were cut to assist drainage or mark boundaries and the Moss was probably burnt periodically to encourage the growth of young heather. This probably led, with the cutting of peat, to some surface erosion of the Moss over the past two centuries. Today, despite the imposition of dams across the drainage ditches, the growth of *Sphagnum* and other peat-forming plants is limited.

#### *Maps and surveys.*

The earliest known maps of the Tarn may be found in the estate rent books dated 1760-85 owned by the National Trust and Malham Tarn Field Centre (Fig. 3). The accuracy of many maps of this period is good with respect to field perimeters, and appear to be reasonably accurate when compared with extant wood and field boundaries on the western (Moss) margin. At this time, Tarn Moss appeared in a painting by A. Devis which was subsequently engraved for Hurtley (1786) but the distant view of the Moss is insufficient to yield any useful detail. The first Ordnance Survey covering the Tarn was published on the Six Inch Yorkshire Sheets 133 and 115 dated 1851-1852. These were used to produce the first one-inch map in the later 1850's. They were followed by the second edition quarter sheets 115SW (1909) and 133NW (1910). The first provisional 1:10,560 scale map, SD86NE was published in 1956 but this has no post-1930 revision and is based on the 1910 map. Unpublished surveys of the Moss shore were undertaken by Cambridge University and Tonbridge School (Kent) parties in 1948 and 1952 and copies of the maps are held in the Field Centre library. Additionally a number of aerial photographs dating back to 1946 are available for examination, though most are of poor quality.

#### METHODS

To provide an accurate measure of recent erosion of the peat cliff two survey points were positioned on the Moss using theodolite measurements from a reference line along the east drive. These were used to fix the position of the cliff and allow earlier surveys to be superimposed onto the map. The cliff line was chain surveyed to 0.5 m accuracy as no electronic survey equipment was available at the time. Most of the Moss was also levelled and contoured at 1m intervals. At the time of this survey (May, 1993) the Moss was fully saturated with water from precipitation. Further reference points, which could be used for monitoring were obtained from the pine trees scattered on the Moss. Three trees were used, and their positions are shown in Fig. 4. The 'dead' pine is situated close to the cliff at the southern end of the 'bight' and the tape aligned with the dead stump immediately behind this tree. The 'south' pine and the southernmost 'twin' pine were aligned with the southern edge of Ha Mire Plantation on the east shore of the Tarn. Distances from the east-facing sides of the trunk to the present cliff top were measured with a tape. Measurements were made between 1993 and 1998 and comparisons were also made between the Cambridge University map and the 1910 Ordnance Survey map. Recession rates can also be estimated from the original positions of trees using the 1780 and 1910 maps.

Two methods were used to obtain an estimate of the original extent of Tarn Moss eastwards into the Tarn. East-west profiles of the Moss obtained by levelling were extrapolated to the presumed 1790 Tarn level (ca. 1.3 m below the present level). This is possible because the eastern dome of the Moss is seen to slope towards the Tarn before

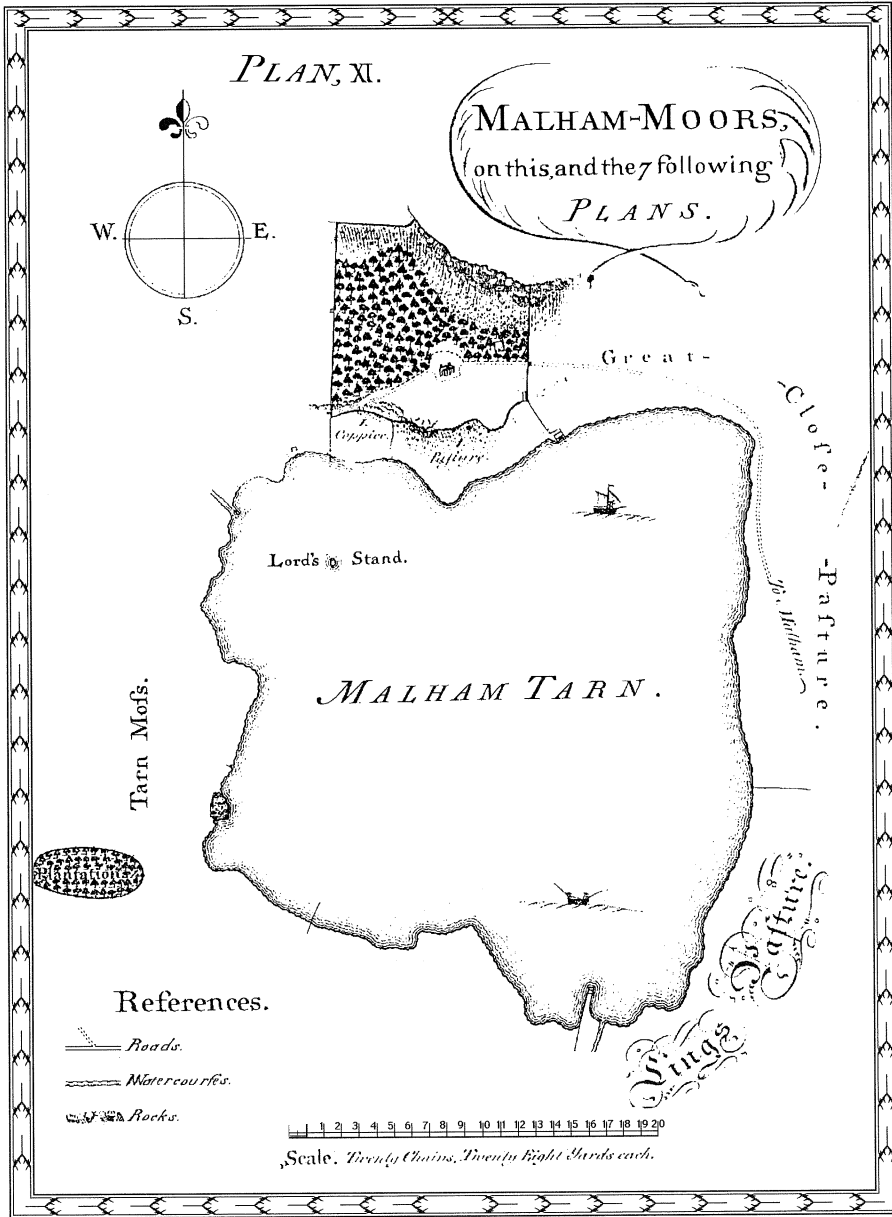


FIG. 3.

One of the rent book maps of Malham Tarn dated to the period 1760-1780.

The positions of the 'Bight' and Spiggot Hill are clearly indicated.

(With permission from the National Trust).

being truncated by the cliff. In one sense this provides a minimum estimate as there has undoubtedly been some surface erosion of the Moss and there was probably a reedswamp fringe extending further out into the water. However, this also assumes that the slope is

constant, and this is unlikely (see below). Second, the area of submerged peat was traced out into the Tarn from a boat using an underwater viewing box providing a clear view of the sediments. The AD1790 margin for the entire Tarn down to a depth of 1.3 m was also estimated with a line from a boat.

## RESULTS AND DISCUSSION

### *1. Rates of change.*

Recent changes in the Tarn Moss shoreline are shown in Fig. 4. The earliest map (ca 1780) was positioned to coincide with the shoreline of the bight prior to the raising of the Tarn level. The moraine, which forms the shore of the bight and is made of hard limestone cobbles and boulders, would have suffered minimal erosion compared with the Moss and thus provides a reliable reference point. Assuming the 1780 map to be accurate, shoreline recession is apparent, particularly to the north, in the vicinity of the inflow of Tarn Beck. The 1850 Ordnance Survey and the 1910 survey show a small peat island near the inflow. This is not visible on the 1946 air photograph but its submerged remnant could be seen in 1993 (Fig. 4). The outlines shown in the air photographs of 1946 (not shown) and 1973 are similar to the 1993 chain survey, but the northern part of the Moss seems to have been eroded to a greater extent than the southern part. The results presented in Table 1a show that the rate of recession appears to have been erratic, partly due to inaccuracies of the surveys and estimates but also due to the piecemeal loss of peat to the Tarn. Along the cliff edge, a series of clefts occur parallel to the shore resulting in the loss of blocks of peat up to 1m wide at a time (Fig. 6). Furthermore, surface creep of the upper layer (ca 30 cm) of peat can often be observed leading to a slice of peat sliding into the Tarn making cliff recession impossible to gauge accurately. The least 'noisy' data set is that measured from the 'twin' pine which suggests that the rate of erosion has changed little over the past 200 years. These losses can be used to obtain an annual cliff recession rate of 4-10 cm (mean 7 cm) equivalent to an annual loss of peat of about 65 m<sup>3</sup> (8 tonnes dry wt a<sup>-1</sup>.) from the full length of the cliff. This estimate is somewhat lower than that which can be calculated from the Cambridge University/Tonbridge School surveys of 1948-52 which is ca 15 cm a<sup>-1</sup>. Unfortunately, there are uncertainties regarding the exact survey date of the earlier 1910 Ordnance Map so this estimate is a maximum possible rate. Looking at the sequence of erosion rate estimates over time for the 'dead' pine location (Table 1b) it is apparent that the rate of recession has declined in recent years. However this may be misleading since the most recent data were obtained over shorter time spans making them more prone to error by the piecemeal nature of the erosion.

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FIG. 4. (opposite)

The west shore of Malham Tarn adjacent to Tarn Moss showing the changes which have taken place according to a number of surveys, the most recent being the 1993 chain survey. The two crosses served as theodolite reference points for the most recent survey, the 1909/10 Ordnance Survey and the 1973 air photograph. The rent book map of ca 1780 was positioned in the Bight using the 1790 shoreline as a reference point. Pine trees mentioned in the text as reference points are: d 'dead' pine; s 'south' pine; t 'twin' pines. The 'projected margin' is the inferred maximum extent of Tarn Moss prior to erosion based upon underwater surveys and projection of the dome slope to the pre-1791 water level.

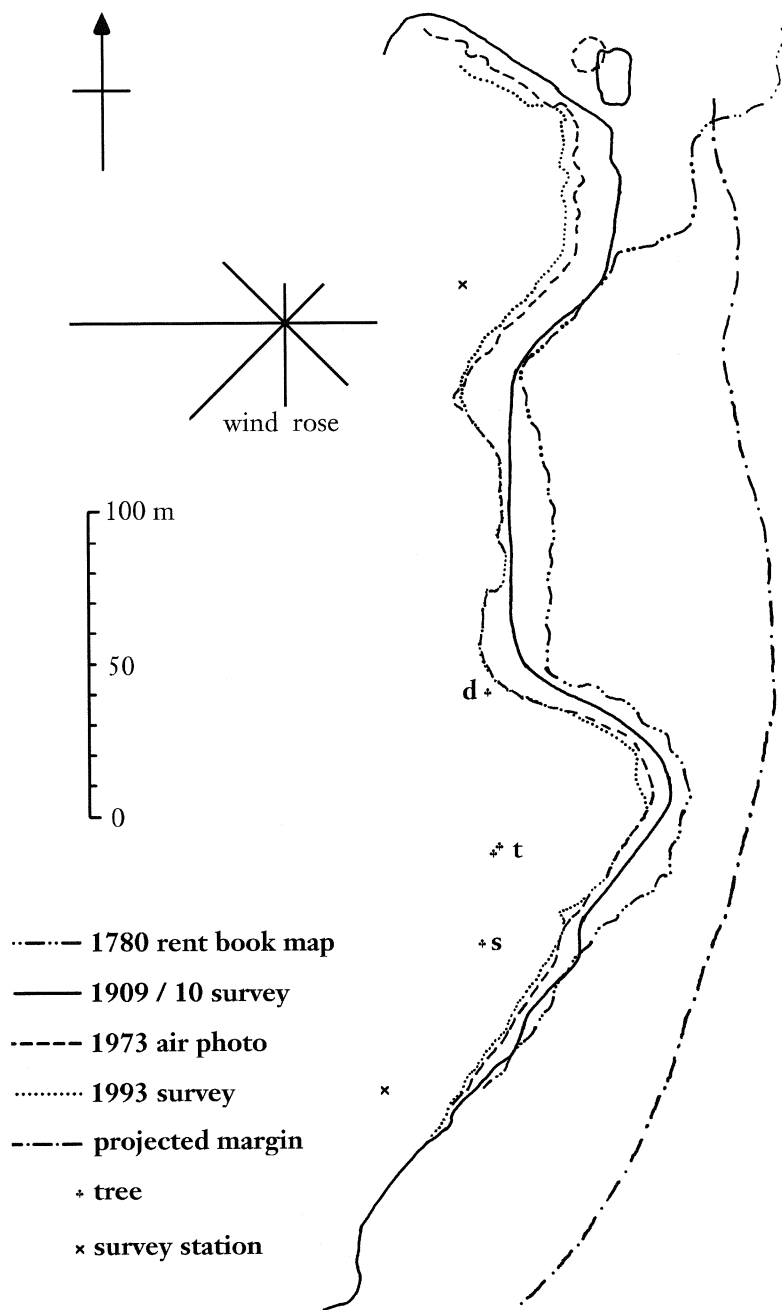


TABLE 1(a) *Distance estimates (m) to the peat cliff from three pine trees on Tarn Moss.*

Source	date	'Dead' pine	'Twin' pine	'South' pine
Rent book map	c.1780	22	50	50
Ordnance Survey	1910	14	36	30
Air photo	1946	9	39	20
Air photo	1973	4.5	29	20
Tape	1993	4.1	30	21
Tape	1998	4.1	29	20.5
Difference	1780-1998	-18	-21	-9.5
Annual rate cm a <sup>-1</sup>	1780-1998	8	10	4

(b) *Recession rates estimated from the 'Dead pine' since ca 1780.*

Date	Difference from 'Dead' pine to present shoreline (m)	Rate of recession cm.a <sup>-1</sup>
c. 1780	22 - 4.1	8.2
1910	14 - 4.1	11.3
1946	9 - 4.1	9.2
1973	4.5 - 4.1	1.6
1993	4.1	0
1998	4.1	

Producing the slope of the remains of the lakeward rand (the rising margin of the moss) to the estimated 1790 water level (Fig. 4) suggests that the original shore extended about 50m beyond the present shore in the vicinity of the promontory and about 80m in the bight. Submerged remains of the eroded moss can be seen at least 13m out from the shore, and a prominent peat shelf can be seen off the southern cliff. Both Dr M. C. F. Proctor and Dr J. H. Tallis (*pers. comm.*) have pointed out that the margins of raised bogs can be steep, so that producing the rand slope to the water's edge may not be valid, even though the slopes used here correspond closely to those obtained in the deep profiles of Pigott & Pigott (1959, p. 321). The apparently large amount of peat lost from the bight may be the result of instability of a thinner layer of peat sitting on the mound of moraine. Using this reconstructed margin, the area of the Tarn with the Moss intact was about 52 ha, 10 ha less than it is today (Fig. 5). Holmes (1965) noted that "artificial raising of the Tarn in 1791 has exposed a small island of glacial drift" (*i.e.* that of the bight). This cannot be correct as it is clearly shown on the 1780 map, which predates the water-raising events but which Holmes might not have seen.

With a peat cliff length of 450m and mean height 2.3 m (including 0.3 m of peat lost



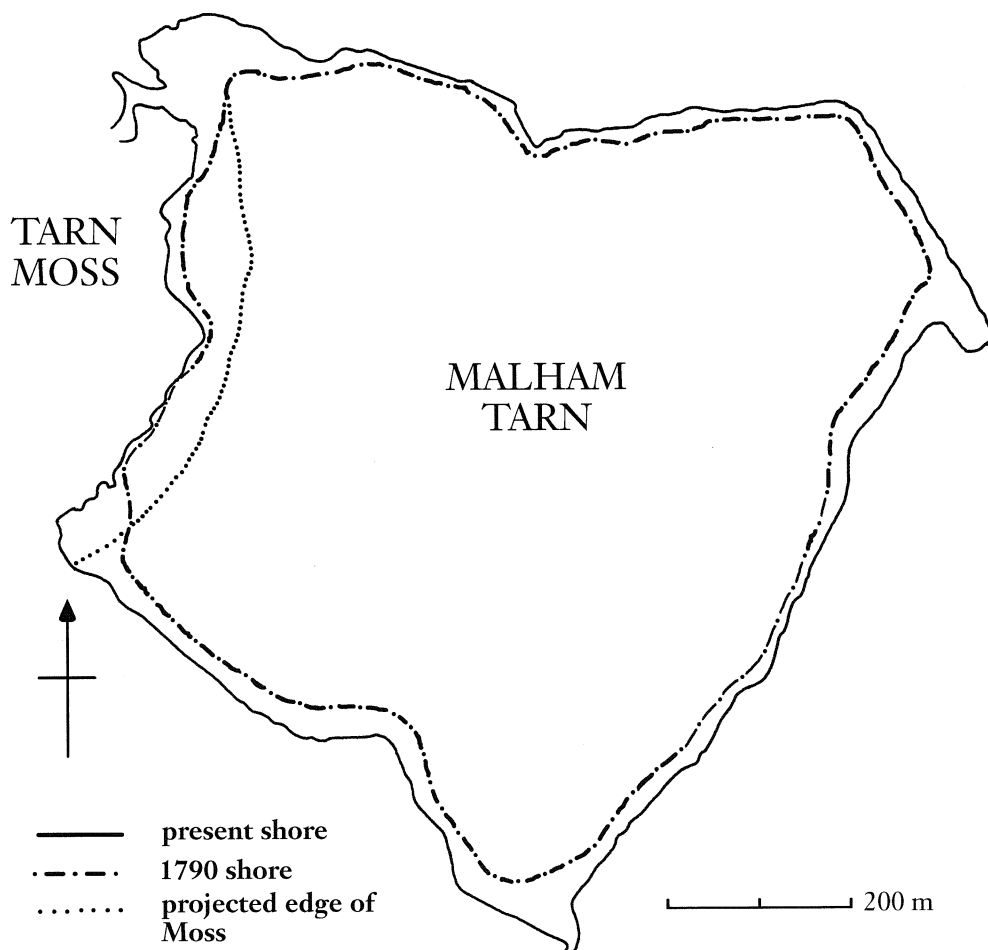


FIG. 5.

Malham Tarn showing the present shore and the shoreline with the depth of water reduced by 1.3 m used as an estimate of the 1790 water level. The inferred maximum margin of the Moss is also indicated.

below current lake level), about 30,000 m<sup>3</sup> of Tarn Moss would have been lost by cliff erosion if the projected margin estimate is correct. This is equivalent to about 3800 tonnes dry wt of peat. If, however, the margin was much closer to the present shore, then the estimate is too high. Dr. M. Proctor drew the author's attention to Branxholme Wester Loch near Hawick (Borders) which is a small calcareous water body showing some similarities with Malham Tarn. This loch is bordered by a small raised bog and separated by a strip of carr and fen swamp. Although there is no present evidence for this at Malham Tarn, a marginal strip of carr may well have been present prior to damming, together with a steeper rand. This morphology makes more sense when changes in the Tarn sediments are considered.

## 2. Peat erosion and the Tarn sediments.

Peat erosion following the presumed 1791 event has had significant implications for sedimentation in Malham Tarn. A series of sediment cores spread widely over the Tarn basin showed a marked change in sediment characteristics at a depth of 25-30 cm. Below this depth the sediment consists of a fairly pure cream-coloured marl containing about 90% calcium carbonate, 5% silt and 5% organic matter. Above is a dark grey mud consisting of about 66% calcium carbonate 9% silt and 25% organic matter. The transition is sharp and according to measured sedimentation rates using carbonaceous particle analysis and marl deposition rates (Pentecost, 1984; Neil Rose, *pers. comm.*) the transition seems to have occurred in the late 18th C. This implies that the sedimentation of non-carbonate material increased significantly after this period. The upper dark layer of sediment of Malham Tarn is estimated to contain about 4000 tonnes organic matter (dry wt) of which, about 3200 tonnes is assumed to be peat. This assumes an even spread of sediment over the non-rocky part of the Tarn floor. Given the recent cliff erosion rate of 8 tonnes  $a^{-1}$ , an additional source of organic matter needs to be sought as this rate falls short of the quantity estimated in the Tarn sediment (it amounts to about 1600 tonnes). It is also apparent that an indeterminate amount of organic matter is washed out of the Tarn in suspension but it is uncertain how much of this material is due to recent plant growth. There has also been an undetermined amount of carbon deposited from the atmosphere as the result of industrial pollution. In addition, the increase in silt and clay deposition in the Tarn is substantial, while the inorganic content of the peat is negligible. A further source of allochthonous (*i.e.* catchment-derived) organic matter and silt may be the flooded soil of the lake margin. Since the higher levels of organic matter and silt deposition continue to the present day, further sources are required since the flooded soils should have been eroded quickly at the exposed edge of the Tarn following the 18th century damming. The most likely source of this additional silt and clay is increased erosion from land within the catchment itself due to more intensive grazing of the surrounding land. It is also possible that the Great Close cattle market, where up to 5000 head of cattle were concentrated near the East shore up to the middle of the 19th C. (see Hurlley, 1786, Raistrick, 1947), also had an impact on catchment erosion. Examination of the organic fraction of the cores above 25 cm depth reveals remains of *Sphagnum* which must have come from the Moss but *Sphagnum* was rarely encountered below this level. Since *Sphagnum* occurs throughout the upper 25 cm of the core, Moss erosion has continued unabated since the water-raising events. Given the uncertainties in the calculations, the amount of organic matter estimated to have eroded from the Moss, the amount estimated in the recent sediments seem to be in reasonable agreement when other sources are taken into account. It is worth noting that an average peat cliff recession rate of 7cm per year, which was used in the estimates implies a total recession of about 15m since 1791 which falls well short of the projected margin calculations (about 50 m).

Peat erosion has been well studied in the U.K. The blanket mires which cover large areas of the higher ground in the northern Pennines show serious signs of erosion which has been attributed to burning (Tallis, 1987), natural instability of the peat cover (Tallis, 1985) and climate change, particularly the drier conditions prevalent about 800 years ago (Tallis, 1997). There is much evidence for intense erosion extending over a period of 1000 years and, although raised bogs such as Tarn Moss have not been investigated in much detail, they too may have been eroding over a similar period (*cf.* pollen profiles in Pigott & Pigott,

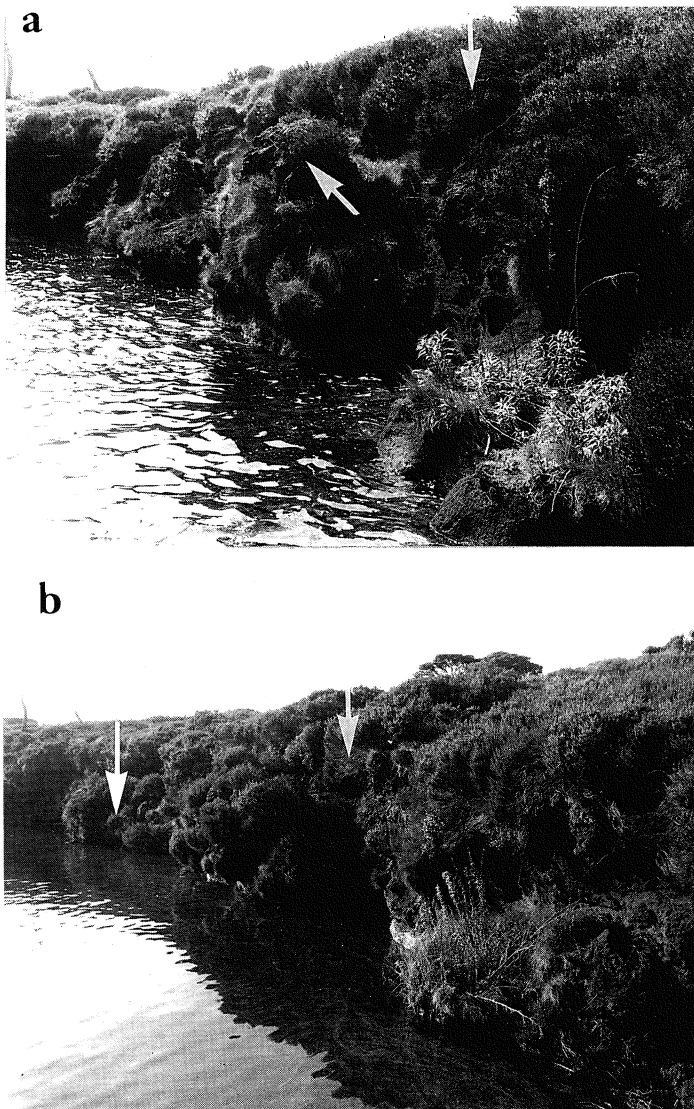


FIG. 6.

Photographs of the peat cliff just below the southern extremity of the 'Bight', looking south along the peat cliff ca 3m high showing the changes which took place in the 5 year period 1993 - 1998.

(a) September 1993.

Left arrow indicates a block of slumped peat which disappeared prior to 1998. Right arrow indicates a clump of ling which can be used as a reference point for the 1998 photograph.

(b) September 1998.

Left arrow indicates a large area of slumped peat carrying ling. Right arrow shows the reference point. During the period the margin of the peat shore showed small irregular changes caused by slumping of the peat. 'Dead pine' can be seen on top of the peat cliff at the extreme left of both photographs.

1959). However, if this is the case with Tarn Moss, which was certainly used for grazing, grouse rearing and peat-cutting in the past, then there is no evidence in the lake core of significant erosion of the peat prior to 1791.

#### CONCLUSIONS

- a) The overall rate of the Tarn Moss cliff erosion is ca  $7 \text{ cm a}^{-1}$  and there is insufficient evidence to indicate a change in rate over time.
- b) The balance of evidence suggests that the raising of the Tarn water level in 1791 significantly increased erosion of the Moss cliff but the evidence is not conclusive. However it is clear that a rapid increase in organic matter sedimentation in the Tarn occurred either in the late 18th C or early 19th C.
- c) Prior to 1791, erosion of the Moss margin was probably occurring but it must have been at a much lower rate, since there is no evidence of enhanced erosion in the Tarn sediments.
- d) There is evidence of increased silt and clay sedimentation in the Tarn which more or less coincides with the increase in organic matter. This could not have come from the Moss but probably originates from the remaining catchment. It may be unconnected to any water-raising event and, perhaps, due to increased land-use within the Tarn catchment.
- e) Estimates of organic matter in the upper Tarn sediments exceeded estimates from the erosion of Tarn Moss. However, given the uncertainties in the calculations, and the likelihood of additional organic sources, the estimates are in reasonable agreement.
- f) While the loss of peat may be as much as 30-50 m along the Moss margin, this makes little sense when considering the evidence from sediment cores and current erosion rates, and a conservative loss of 15-20m peat appears more likely on the current evidence.
- g) Further monitoring of the recession rate is recommended at approximately ten year intervals. This can be easily achieved using the pine tree markers described. Further trees could be used to provide a simple and reliable monitoring programme.
- h) A greater understanding of erosion processes within the catchment could be gained by monitoring the suspended particle concentration at the Tarn inflow and outflow on a regular basis.

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