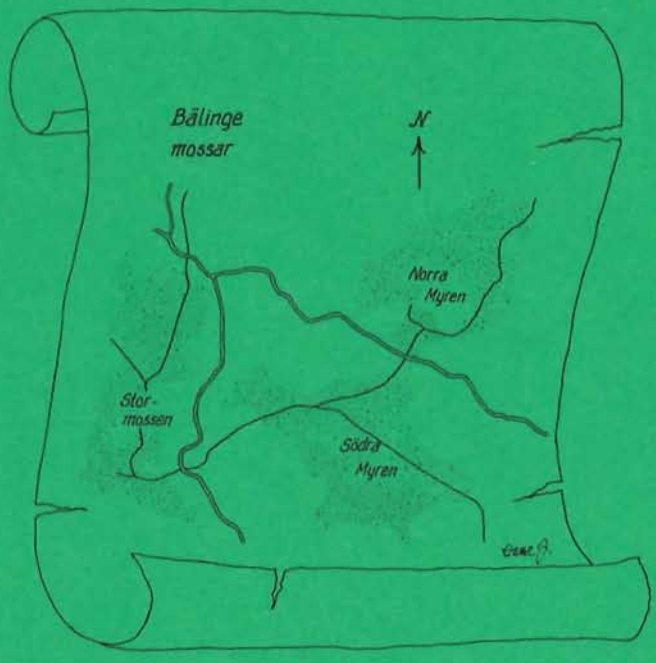
SVERIGES LANTBRUKSUNIVERSITET

THE RISE AND FALL OF BÄLINGE MOSSAR

BÄLINGE MOSSARS BILDNING OCH BRUKNINGSHISTORIA

Mary Mc Afee



Institutionen för markvetenskap
Avdelningen för lantbrukets hydroteknik

Swedish University of Agricultural Sciences
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Rapport 147
Report

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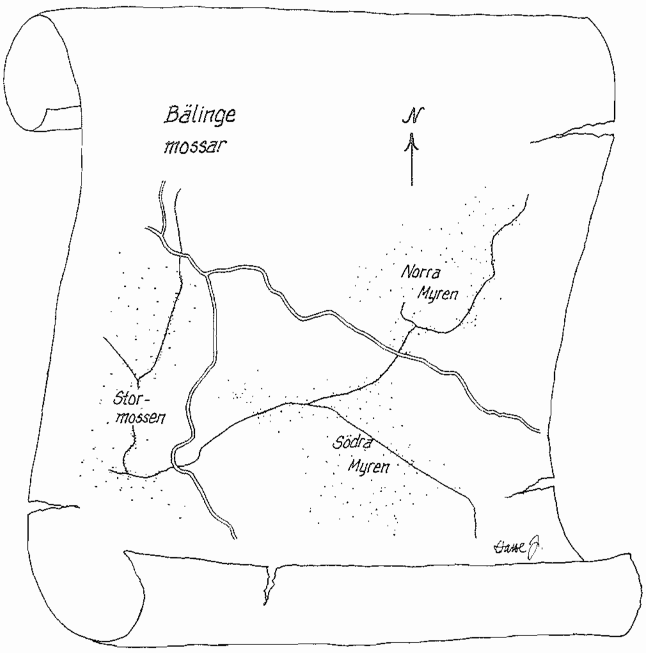

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Mary Mc Afee

Uppsala,
April 1985

CONTENTS page

THE RISE AND FALL OF BÄLINGE MOSSAR

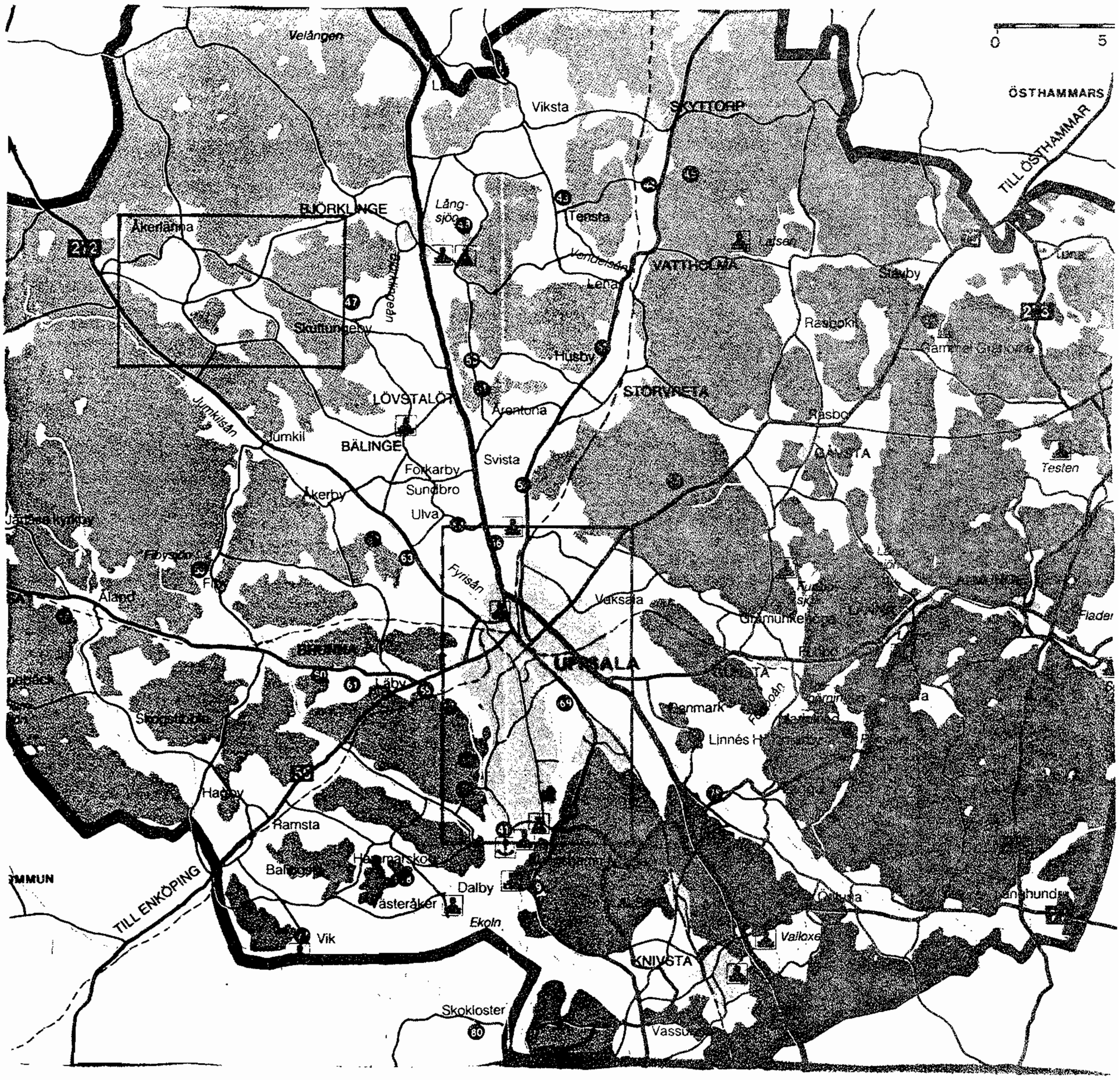


Fig. 1. Map showing Bälinge Mossar in relation to Uppsala kommun.
Scale 1:300,000.

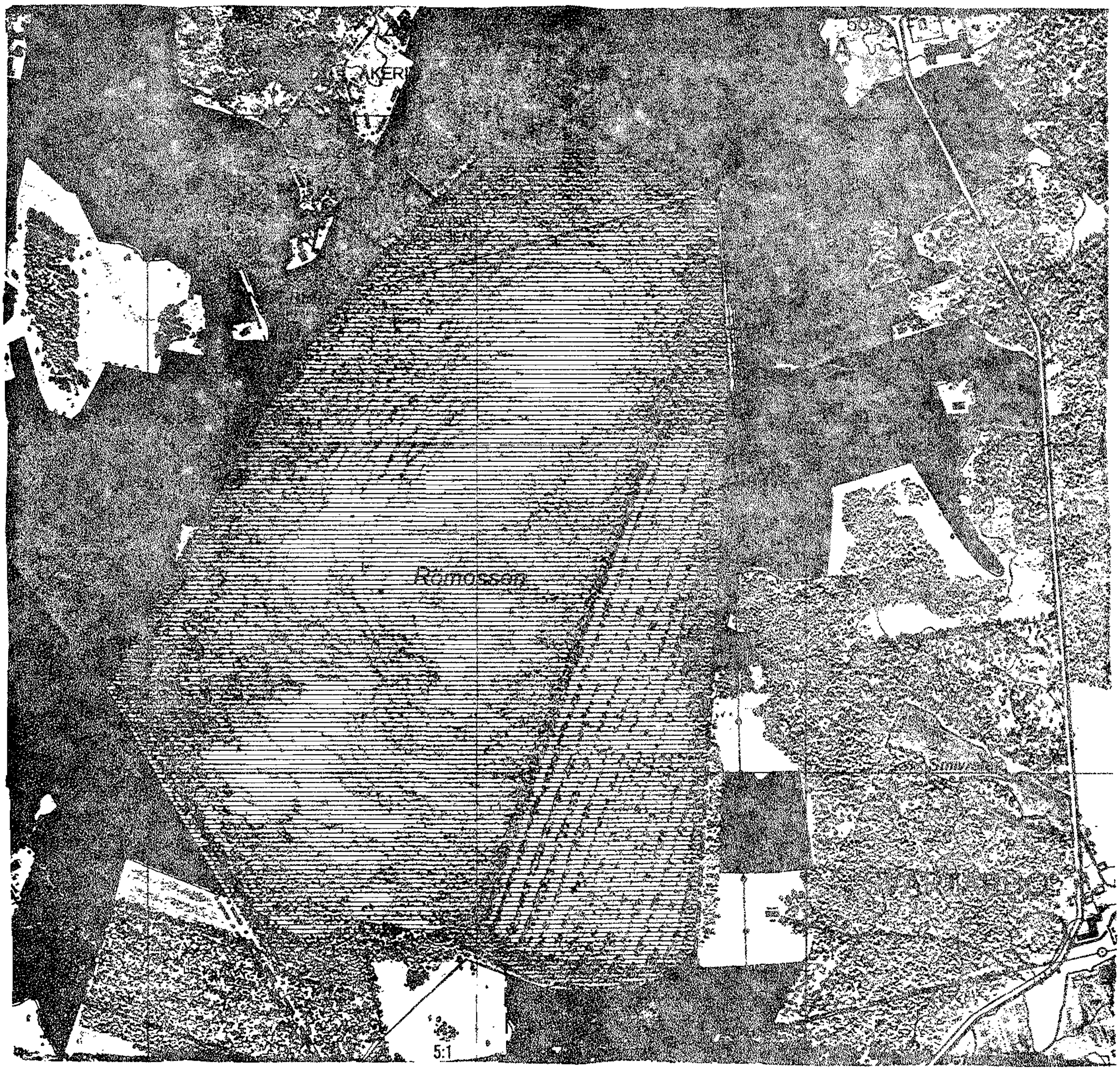


Fig. 2. Section of the relevant economic map (12H 1h Åkerlänna) showing topographical features of the domed mire, Åkerlänna högmosse or Römossen

Scale 1:10,000.

Introduction

Bälinge Mossar is the collective name given to the area of marshes or peat bogs lying 25 km NW of Uppsala (see Fig. 1). The area is shown on topographical map 12H Söderfors SO and on economic maps 12H Oh, Oi, 1h and 1i.
The bogs lie in three large groups given the names Stora Mossen, Norra Myren and Södra Myren, having areas of 7.7, 3.5 and 4.7 km^2 respectively. In the north of Stora Mossen lies a domed mire (högmosse), Åkerlännamossen or Römossen which has an area of about 50 ha. This is a typical concentric domed mire, the topography of which can be seen clearly on the relevant economic map (Fig. 2). The eastern part of this mire has been influenced by man, through drainage and peat cutting.
The majority of the peatland in the Bälinge Mossar area is of the type rheophilous low moor (kärr).
The area is of both historic and scientific interest and has been the subject of investigation for many wellknown Swedish scientists. Most of this interest was shown at the turn of this century and the objectives were:
1) to date climatic changes in Swedish geochronology using the peat stratiagraphy in the Bälinge profile
2) to study the undisturbed peat profile and the natural vegetation from a botanist's viewpoint
3) to study the agricultural potential of the area and the possible fertility of the soil.
This report begins with the history of deposition of the bogs and their development to the present day, Available references to Bälinge Mossar are included, though some are of historic or geological rather than purely agricultural interest. It is clear that the area was well known to and well researched by Swedish scientists of the early 20th Century.

The process of post-glacial emergence and the succession of seas or lakes which covered Sweden during this time has been described by Magnusson and Granlund (1936). Three post-glacial water masses can be distinguished by their fossil remains. The earliest of these was the Yoldia sea, named after its most commom fossil Yoldia arctica. Rapid land rise led to annexation of this water mass from the sea and it gradually became a freshwater lake, colonized by the freshwater mollusc Ancylus fluviatilis from which the lake derives its name. Salt water levels rose again in the South and a transgression from fresh to saline water occurred over much of Sweden. This change is marked by the Clypeus boundary since the brackish water diatom Campylodiscus clypeus then replaced Ancylus. The subsequent saltwater mass came to be known as the Litorina sea after its characteristic fossil, Litorina litorea. At its maximum, the Litorina boundary lay at an elevation of 70 m over Bälinge. Magnusson & Granlund (1936) describe the general succession of sedimentation and deposition of clay and organic matter on the bottom of post-glacial seas.

During the period 1905 - 1912, the peat profile and the natural vegetation of Bälinge Mossar were intensively investigated in a project sponsored by Naturvetenskapliga Sällskapet in Uppsala. Work was supervised by the then docent Rurger Sernander and detailed descriptions of the Bälinge Mossar area, its strata, peat types and vegetation were published by Eriksson (1912). His description of the specific succession sequence was based on his analysis of the peat, gyttja and clay deposits and can be summarised thus:

After withdrawal of the Litorina sea, clay from the surrounding moraine was washed into deeper topographical areas. This clay consisted of irregular bands overlain by a layer of mixed Yoldia, Ancylus and Litorina clays.
Final withdrawal of water was a slow process, leaving relatively plane clay surfaces on which shore mud (stranddy) was deposited. Shore mud was shown on analysis to consist of very fine organic particles deposited in shallow water in ponds closed off from the main body of water by reed ridges. Thus shore mud in this case resembles in its deposition pattern the seaweed banks seen at the coast. Before the mud settled out of suspension, wave action had washed deposits of first clay, then sand and gravel from the moraine into a band along the shore. When the particular bay was cut off completely from the sea, conditions became calmer and gyttja deposition began. Rhabdonema gyttja was deposited in deeper and Clypeus gyttja in shallower water where the fauna was more concentrated in numbers. Thus the mud was covered by first the brackish

Clypeus gyttja, then freshwater gyttja. Dearth of plant remains in these deposits, and the occurrence of freshwater gyttja at a distance from the original shoreline, point to the fact that the lake maintained its area for a long period. Such plant remains as were present consisted of less dense fragments such as Sphagnum leaves and Betula seeds (windborne). Profile appearance at this stage is shown in Fig. 3a.

When the original bay finally became landlocked Scirpus and Phragmites spp. began to colonize the edges of the area, growing on top of the detritus gyttja deposits. Further out from shore, deposition of plankton gyttja continued and as lake depth was reduced by the gyttja deposits semi-aquatic plant colonies grew towards the centre of the lake. Shallow water plants (Najas) partly died out at this stage, to be replaced by species such as Nuphar. Between the Phragmites colonies and dry land an Equisetum species formed a monoculture, giving way to Carex on dry land. Thus the lake closed over and the marsh which remained was quickly overgrown by Salix and Sphagnum, followed by Alnus and Betula (see Fig. 3b).

The marsh was gradually covered by a Betula stand and achieved a more xerophilic nature. Taller evergreen trees with thicker trunks replaced Betula so that, at equilibrium, an almost totally coniferous forest reigned. (see Fig. 3c).

The final stage in development of the profile was stagnation or the recurrence of marsh conditions. This is thought by Eriksson (1912) to have begun at several sites in the forest. In the domed mire area, Sphagnum colonies formed and began to spread. Trees died out as marsh conditions intensified and the moss colonies finally met up to cover the entire area.

There were slight differences in deposition pattern between the domed mire site at Åkerlänna and the surrounding low moor areas. The domed mire site was in the beginning the deepest topographical region. In the shallower areas on which the rest of the marsh was formed the lake was colonized and overgrown more rapidly. The original water depth at the time of annexation from the sea was smaller (1 metre compared to 2) than at Åkerlänna and the process from gyttja deposition to full forest stand took a shorter time. In these shallow bays, the boundary between marine clay and gyttja was fully horizontal. Gyttja was deposited in a slight dome, thickest at the centre of the lake. This had a considerable effect on the subsequent rapid forest growth which became denser at the centre of the lake and contributed most of the organic deposits. Stagnation in these low moor areas began at the edges under eutrophic conditions not favourable to Sphagnum.

The progession of events described by Eriksson (1912) conformed to the Blytt-Sernander and Uppsala school of thought at that time. Sernander (1909) describes the Bälinge peat profile to illustrate his theory of mire formation which is based on the assumption that forest peat was laid down at a particular time due to climatic changes and that the profile thus records climatic changes. The type of profile diagram produced by Eriksson (1912) is of the type proposed by Sernander (1909), see Fig. 4.

Andersson (1909) disputes the theory of dating from the tree remains found in peat, arguing that a single layer of forest peat did not occur and that such remains as were present were distributed throughout the depth of the profile. The Uppsala school assumed that presence of tree stumps and trunks prove that at the time of their growth, the surface was dry and that trees died to form a new layer of forest peat when the climate became wetter. Andersson (1909) disputes the occurrence of wet and dry periods and argues that patches of the forest destroyed by fire, for example, were colonized by Sphagnum spp. which gradually led to oligotrophic conditions. Regarding Bälinge Mossar, or more specifically its domed mire, a hypothesis was proposed by Haglund (1909) to the effect that the change from forest to marsh which occurred there could have been the result of primary cultivation and cutting down of forest. Eriksson (1912) specifically considers and refutes this hypothesis, noting that in his intensive investigations around this area he found no signs of burning or cultivation.

Granlund (1931 & 1932) takes up the issue of dating changes in climate as reflected by peat deposits. He used the technique of pollen analysis developed by von Post to produce probable times for the horizon changes in the domed mire and its lagg area. Granlund (1931) gives a full pollen diagram for Åkerlänna Högmosse and compares this to a partial diagram for the lagg. Magnusson & Granlund (1936) produced a table summarising changes in the Late Quatenary period. Stages in the development of Bälinge Mossar can be fitted onto this timetable (see Fig. 5).

Peat stratiagraphy

Eriksson (1912) carried out detailed analysis of the peat, gyttja, mud and clay deposits at two points in the Bälinge Mossar area - The domed mire and an area of low moor peat, Södra Myren. Material found in each layer was analysed and classified botanically, sometimes with the help of microscopic and chemical data. The results obtained were used by Eriksson (1912) to draw the diagrams shown in Fig. 4.

The lowermost layer consisted of blue-grey moraine clay which was found by

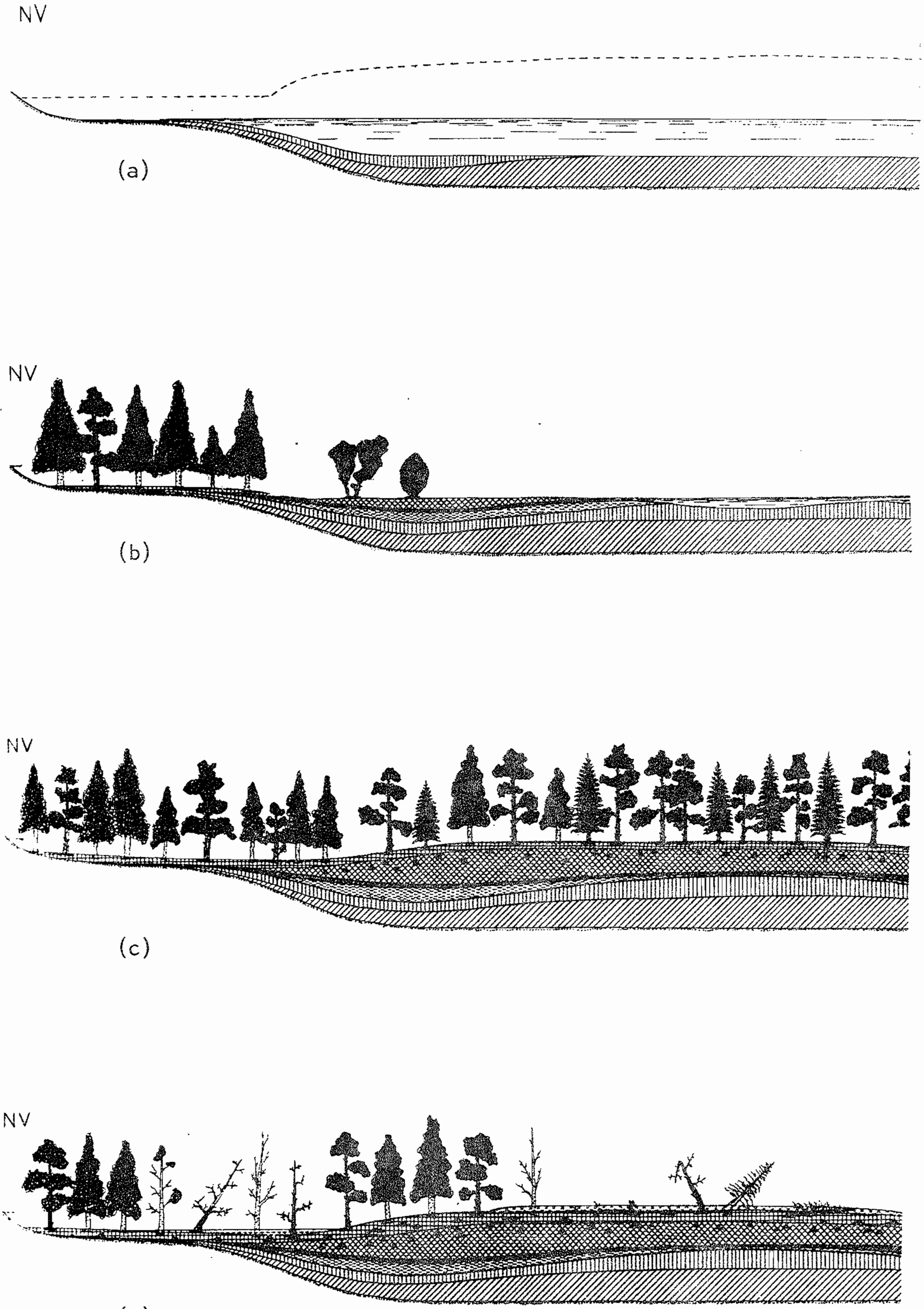
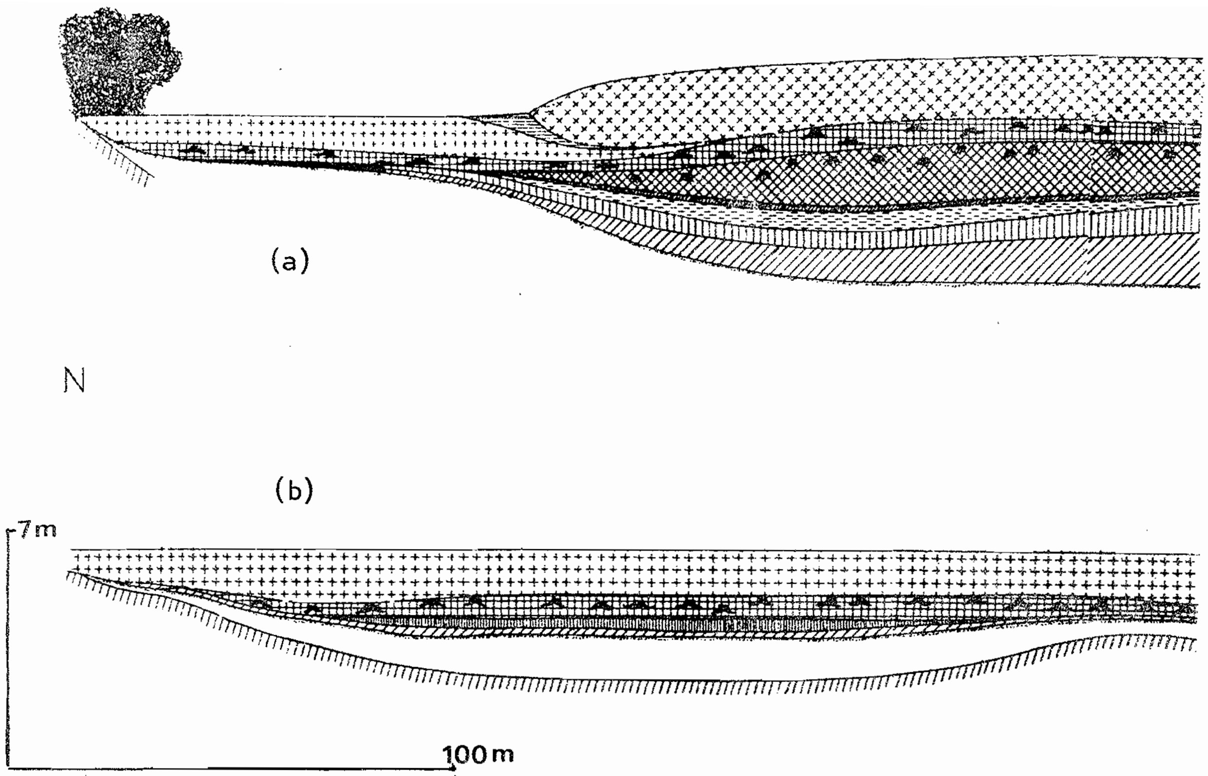


Fig. 3. Stages in the development of Bälinge Mossar (Stormossen area)
a) Atlantic period,
b) Beginning of Sub-boreal time,
c) End of Sub-boreal time,
d) Beginning of Sub-Atlantic time.
(After Eriksson, 1912)



KEY to Figures 3 & 4

Sphagnumtorf	Sphagnum peat	*Skogstorf*	Forest peat
Amblystegiumtorf	Amblystegium peat	*Kärrtorf*	Fen peat
Starrmosstorf	Carex peat	*Phragmitesgyttja*	Phragmites gyttja
Detritusgyttja	Detritus gyttja	*Marin gyttja*	Marine gyttja
Dy	Dy	*Marin sand och lera*	Marine sand and clay
Brack och sötv.-gyttja	Brack and freshwater gyttja	*Morän*	Moraine

Fig. 4. Final stage in the development of Bälinge Mossar

a) Åkerlänna domed mire (högmossen), 1906

b) Södra Myren before drainage, 1906

(After Eriksson, 1912)

probing to be several metres thick even at a short distance from the moraine outcrop. Directly over the clay, and separating it from the gyttja, was a 10 cm thick layer of sand and small stones, covered in some places by a 1 - 10 cm thick layer of black, well humified shore mud (stranddy). The organic layers above this level were slightly different in the two areas investigated by Eriksson (1912). The stratiagraphy of the domed mire region is described first, then any deviations shown in the Södra Myren profile are described.

The gyttja deposit in the domed mire area was found to consist of two distinct layers. Microscopic analysis showed the lower layer to be of brackish water origin and consisting of remains of a diatom, Rhabdonema. This gyttja was grey-green in colour, elastic and lacking in fossil remains. The upper gyttja layer (Clypeus) was pure green, less elastic and relatively rich in fossils. The layer above this was brown detritus gyttja formed chiefly from Scirpus remains. This was overlain by yellow Phragmites gyttja, a low density deposit formed from phragmites rhizomes.

Above this layer, material was classified as fen peat (kärrtorv).

The lowest layer was Equisetum, which gave way to Carex remains. Above this was a thick layer of heterogenous peat consisting of bush and tree remains. The uppermost layer of this forest peat contained much woody material, with Pinus and Betula trunks showing 4 - 6 mm annual rings.

The uppermost layer of the domed mire consisted of Carex-Amblystegium (brunmosstorv) at the edges with a thick mat of Sphagnum forming the dome.

Södra Myren had a similar profile but in its case, it was impossible to distinguish between the two types of plankton gyttja. The gyttja was overlain by a brown, well humified mud (dy) instead of Scirpus and Phragmites gyttja. The remaining layers of the low moor profile consisted of a layer of forest peat, then finally a Carex-Amblystegium layer.

The Södra Myren profile is a typical example of a fertile Swedish lowmoor or fen peat (Osvald, 1937).

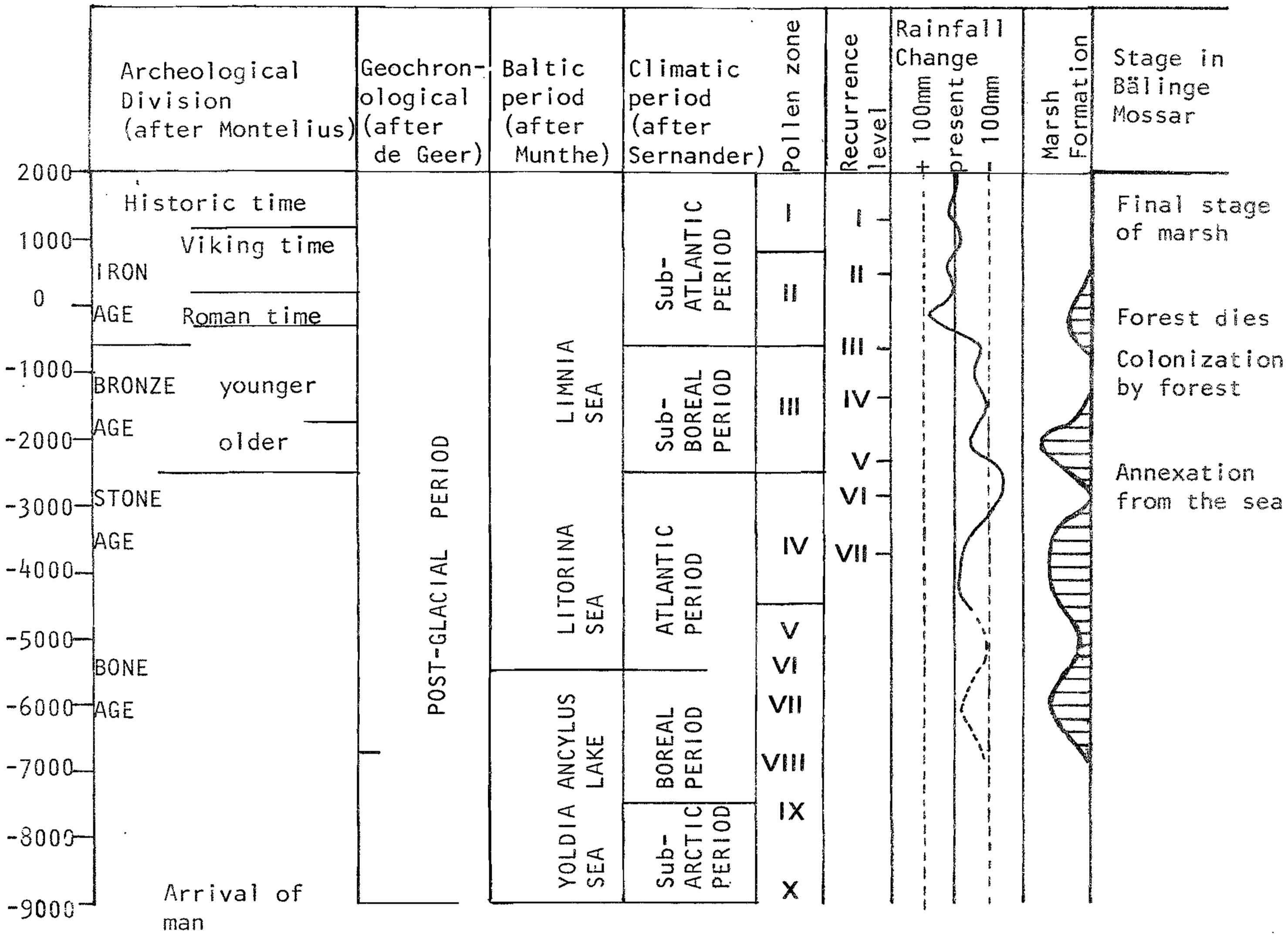


Fig. 5. Phases in the Late Quaternary period classified according to various systems and showing the approximate time of stages in the development of Bälinge Mossar.

(After Magnusson & Granlund, 1936)

The Fall ...

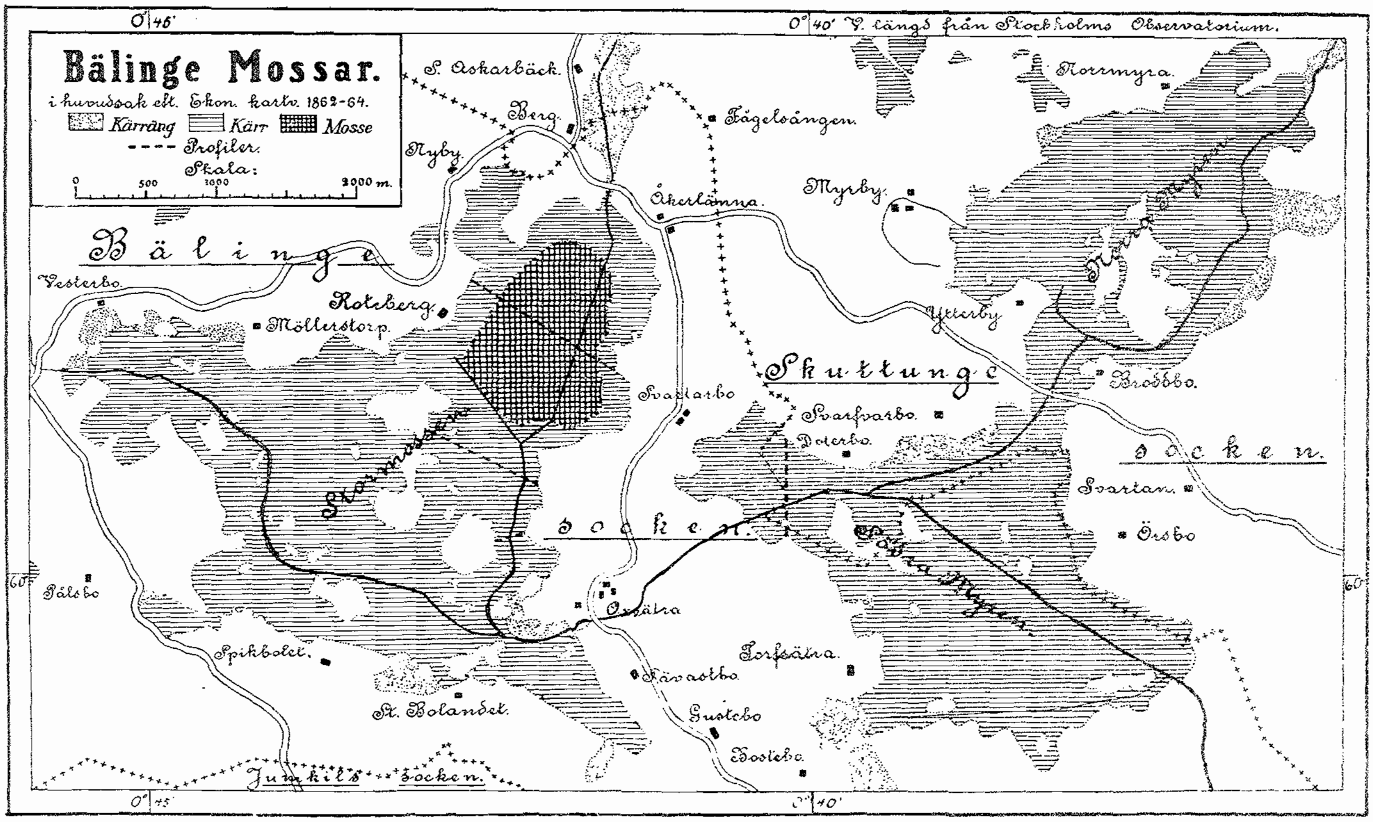
The scientific interest in Bälinge Mossar shown by Sernander (1909), Eriksson (1912) and other scientists was initiated after an important development in the history of the area - the land had come to the attention of the agricultural sector and a drainage project had already been begun in 1904. Eriksson (1912) set out to record the undrained peat profile before it, too, was disturbed. There had already been some drainage activity in the area, as reported by Eriksson (1912) but this consisted of a few main canals installed around 1840. The extent of these is shown in Fig. 6 after maps from 1860. That these canals were not effective in draining the area is obvious from a report by Eriksson (1912) that in the 1860's, the inhabitants were able to take flat-bottomed boats out over the marshes during high water periods. Deepening of these canals was carried out around 1870 but this measure did not improve drainage in the area.

It is possible that the first move to carry out intensive drainage was prompted by a farmer in the area, Erik Ersson from Lindberg. He carried out some drainage, then sued the landowners downstream to provide an outlet for the drainage water, according to the Swedish water law (von Feilitzen, 1916). Official interest was now awakened and at the end of the 19th Century the Peat Cultivation Society (Svenska Mosskulturföreningen) was asked to investigate the agricultural potential of the Bälinge Mossar area. This work was carried out by Tolf (1897). He described the vegetation and peat type at various sites in the area as follows:-

Norra Myren - was then colonized by grass and Carex species, underlain by a thick mat of Amblystegium moss. The peat itself was described as black, well humified and generally fertile. Both the vegetation and the peat type indicated a very high cultivation potential.

Södra Myren - resembled meadow rather than marsh, the soil being firm and the peat well humified. The main vegetation was Carex, with patches of Amblystegium and occasional bushes. The peat, which was shallow in places, lay on a thick bed of clay. This area was thought to have as high an agricultural potential as Norra Myren.

Tolf (1897) carried out similar investigations on all parts of the marsh complex, noting the vegetation, peat type and cultivation potential of each area including the domed mire. He concludes his report on the area by expressing his amazement that such a potentially valuable, large area had remained undeveloped for so long and he urged immediate drainage.



KEY to Figure 6

fen peat

fen meadow

domed mire

road

+ + + + + + + + townland boundary

sampling line

Fig. 6. Map of the Bälinge area drawn from 1862-1864 maps and showing the extent of drainage carried out in 1840

(After Eriksson, 1912)

Wellenius (1916a & b) summarised the subsequent drainage of the area. The pre-drainage investigation of the peat and canals was carried out in 1897-1898. The area was surveyed and mapped and the proposed drainage canals dimensioned. Over 6 thousand core samples were taken and the peat material analysed and described. Complete records of sites and results of core sampling are still available in Lantmäteriets arkiv, Uppsala.

The predicted cost of this drainage was around 177,000 kronor, and the investigation was completed in 1898. The area involved was 1830 ha.

Legal protests and queries from downstream landowners and Uppsala town had to be dealt with before work could begin. One objection was that draining of Bälinge Mossar would increase high water levels in Björklinge river and destroy bridges and installations. These problems were finally dealt with and work began in 1904, in the Norra Myren area. By 1908, when work was completed, 60 km of canal had been excavated and the cost of the operation had risen to 182,000 kronor. The extent of drainage at this time can be seen in Fig. 7.

The new drainage canals subdivided fields and farms so much that in 1906, legal partition of Norra and Södra Myren was carried out to rationalize property ownership.

Subsequent cultivation of the drained marshes began almost immediately. Eriksson (1912) reports the change which occurred in the area during his time there. By 1906, much of Norra Myren had been drained and ploughed and was under cultivation. By 1912, the tilled area included almost all of Stormossen (except the domed mire) and the northern part of Södra Myren.

Sahlin (1916) describes the post-drainage reclamation of Bälinge Mossar. Some areas colonized by sparse bushes or trees required clearing with axe and spade. For the most part, however, the marshes could be ploughed directly after drainage thus minimizing reclamation costs. No particular crop rotation was practised in this region at first. Much of the land belonged to farm properties some distance away and such areas were usually grazed rather than tilled. Tilled areas had a general pattern of 1,2 or 3 years of oats followed by 4 to 6 years of grass. Sahlin (1916) commented on the success of this system in controlling weeds.

During World War I, 1914 - 1918, tillage became more intensive due to government subsidies (Barrner, 1947). After the war, roads were built through the area and some bridges were re-built. Dredging and maintenance of canals was carried out as early as 1912-14, since some deterioration of canal banks had occurred. No further maintenance was carried out until 1924 when, due to overgrown ditches and land subsidence, the situation had become critical (Barrner, 1947). The necessary repair work was finally carried out between 1924 and 1927.

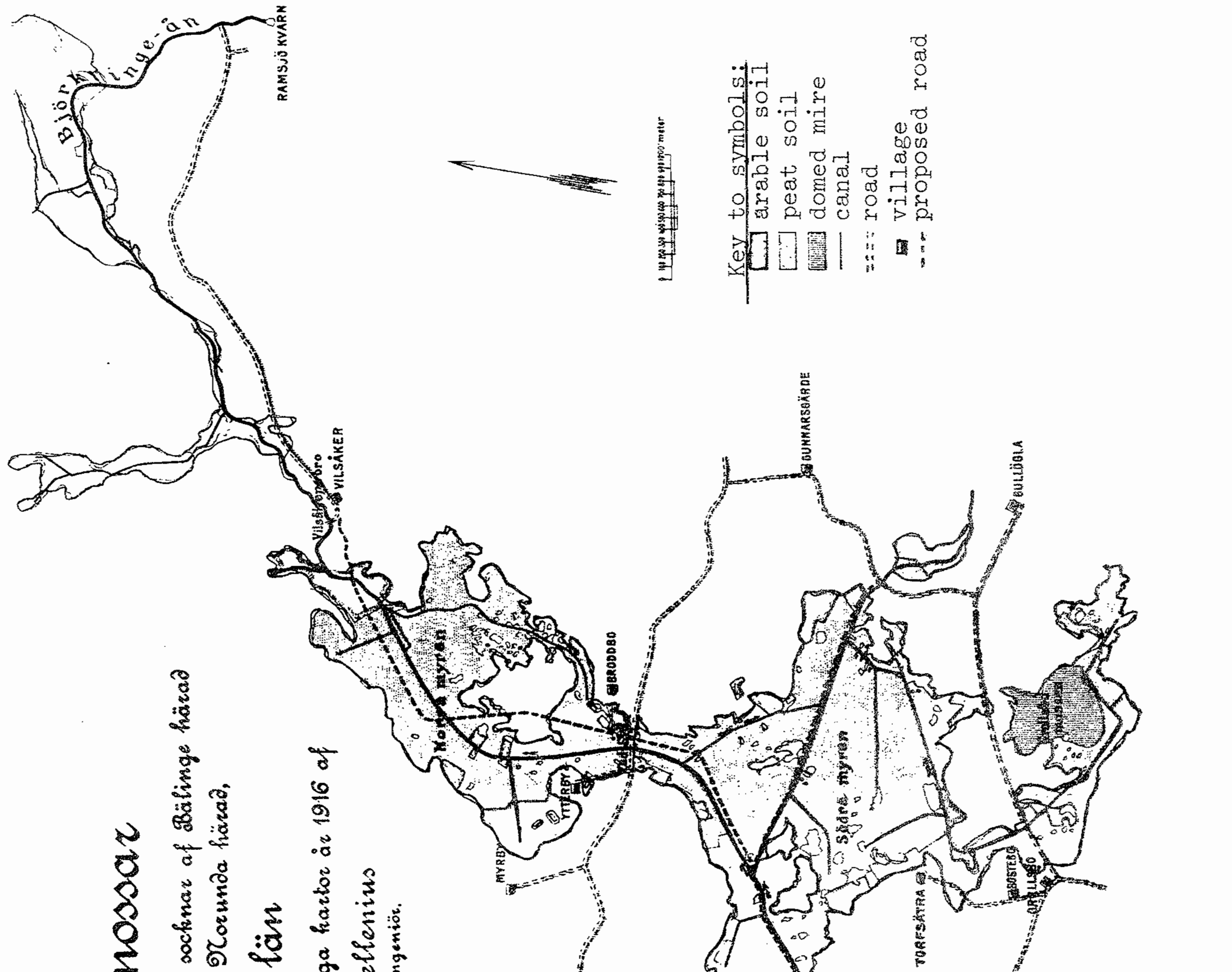


Fig. 7. Map of Bälinge Mossar drawn from available maps in 1916 and showing the 1904-1908 drainage canals
(After Wellenius, 1916a)

Fall (1944) and Barrner (1947) describe the deterioration of drainage canals during the early 1930's. A comparison of land levels from 1898 and 1938 surveys (maps of Bälinge Mossars torrläggningsföretag, 1898 & 1938) shows the surface subsidence to have been 50 - 150 cm during the period (see Figs 8 & 9). In 1936, canals were surveyed for dredging and deepening but it was found that these remedial measures would not be sufficient. In 1937, permission was sought for a new drainage project. Comprehensive mapping of the area was carried out and over 1000 core samples taken to determine depth and nature of peat. Table 1 shows the results of core sampling in 1898 and 1938 for a particular area of Södra Myren, that described by Eriksson (1912), see Figs 4 - 6.

Table 1. Results from core sampling of an area of Södra Myren showing changes in peat thickness between 1898 and 1938. (After records of Bälinge Mossars torrläggningsföretag 1898, 1938).

1898		1938		
Point	Peat type and depth	Point	Peat type and depth	Loss (cm)
4209	2-3 m torvdy on clay[1]	283	1.35 m dyjord on clay[1]	65 - 165
4217	2.5 m ''	280	2.10 m ''	40
4218	3.0 m ''	279	1.75 m ''	125
4238	3.0 m ''	290	1.00 m ''	200
4229	2.2 m ''	281	1.80 m ''	40
4219	2-3 ''	282	1.50 m ''	50 - 150

[1] torvdy = poorly humified peat on gyttja, dyjord = well humified peat

Note that while results from the 1938 investigation are measured to the nearest 5 cm, those from 1898 are only approximate values. Some depths are measured to the nearest 10 cm, others to the nearest metre.

An area of 1240 ha was encompassed by the 1938 drainage project. Work was begun in 1939 and completed in 1945. World War II led to delay in completion and increased the cost of drainage to a final sum of 783,000 Swedish kronor.

The area was intensively drained at this stage, with drains 20-80 m apart opening into the main canals. Positioning of field drains was the best possible as regards drainage effectiveness but they considerably impeded subsequent farming operations (Öhman, 1966). Some fields with a clay subsoil were tile-drained and in some deeper areas, wooden covered ditches were installed.

Crop rotation after the 1938 drainage was usually one year each of fallow, rye and grass, then a spring cereal for 2-3 years. As has been stated, much of the land belongs to farms lying some distance away and on such land, the above rotation could not be followed due to travel and transport problems

Instead, a more extensive system of grass for 4-6 years, then oats for 1 year was practised. The hay saved was stored in the many barns which are situated in the region and the aftergrass was grazed by dry cows and young stock. In the 1938 drainage plan, provision was made for regular maintenance of canals. Banks were to be cleared of grass and bushes every year, and the canals to be dredged every 3 years.

Despite the fact that the planned maintenance work was carried out as planned, much of the region is now in need of re-draining. Subsidence has continued since 1938. Göransson & Hellsten (1964) report that peat had completely gone from some areas and in others the watertable was sufficiently high to inhibit crop growth. From a survey carried out in 1964 a new set of levels for the area shown in Fig. 8 are available. In Fig. 9 these 1964 levels are compared to those obtained in the most recent survey, 1984.

All elevations shown in Figures 8 & 9 are based on a local fix point and do not refer to height above sea level. There is therefore no need to correct for upward land movement during the 80 year period spanned by the surveys and elevations for a particular point on the map can be compared directly. A glance at the elevations shows the general trend of decreasing values due to peat subsidence.

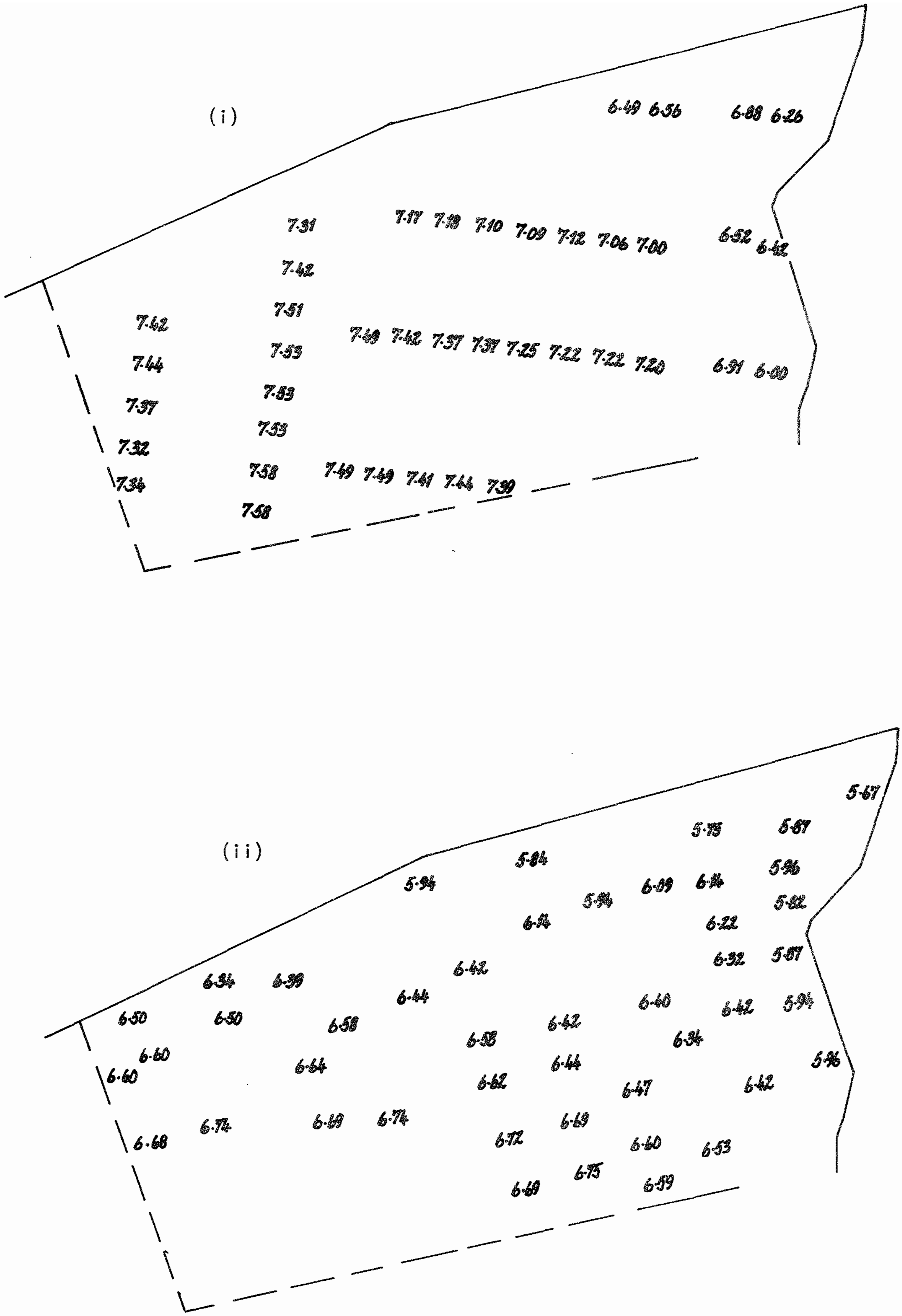
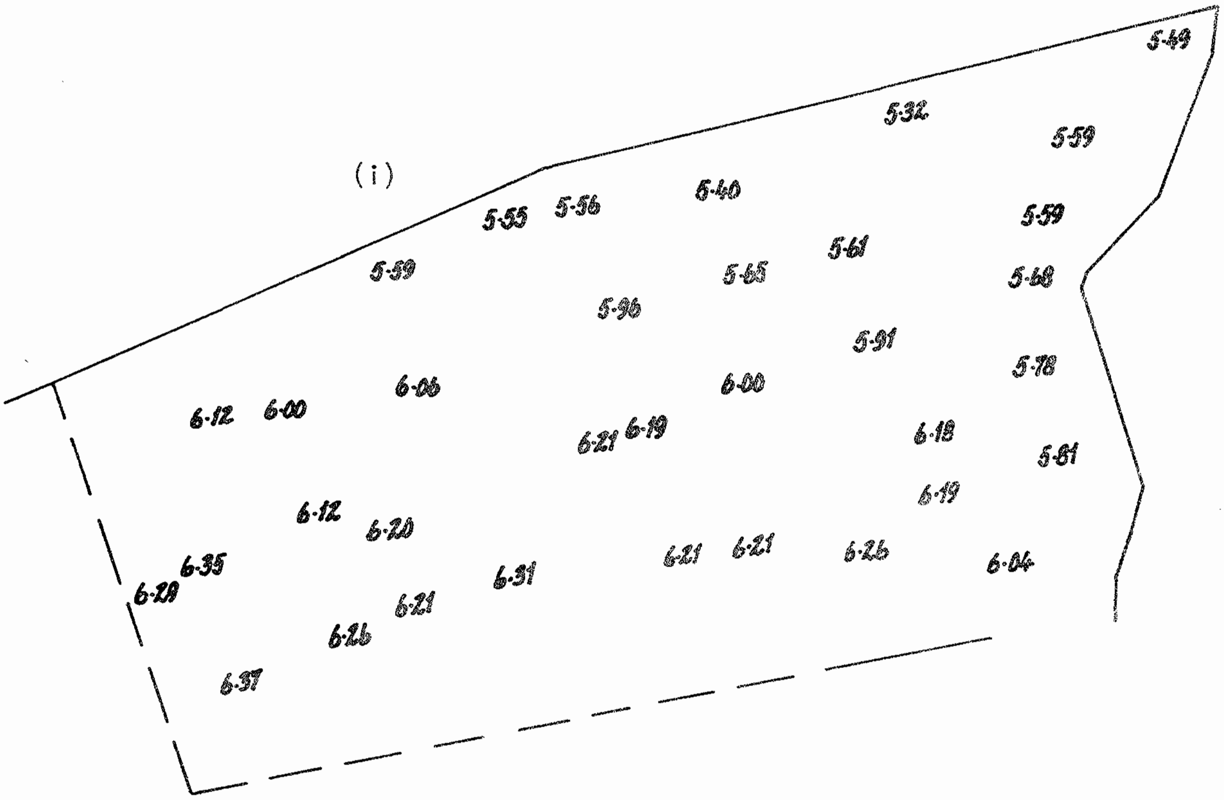


Fig. 8 . Levels obtained from (i) 1898 and (ii) 1938 surveys of a part of Norra Myren, showing how its surface has subsided in the 40 year period.

(i)



(ii)

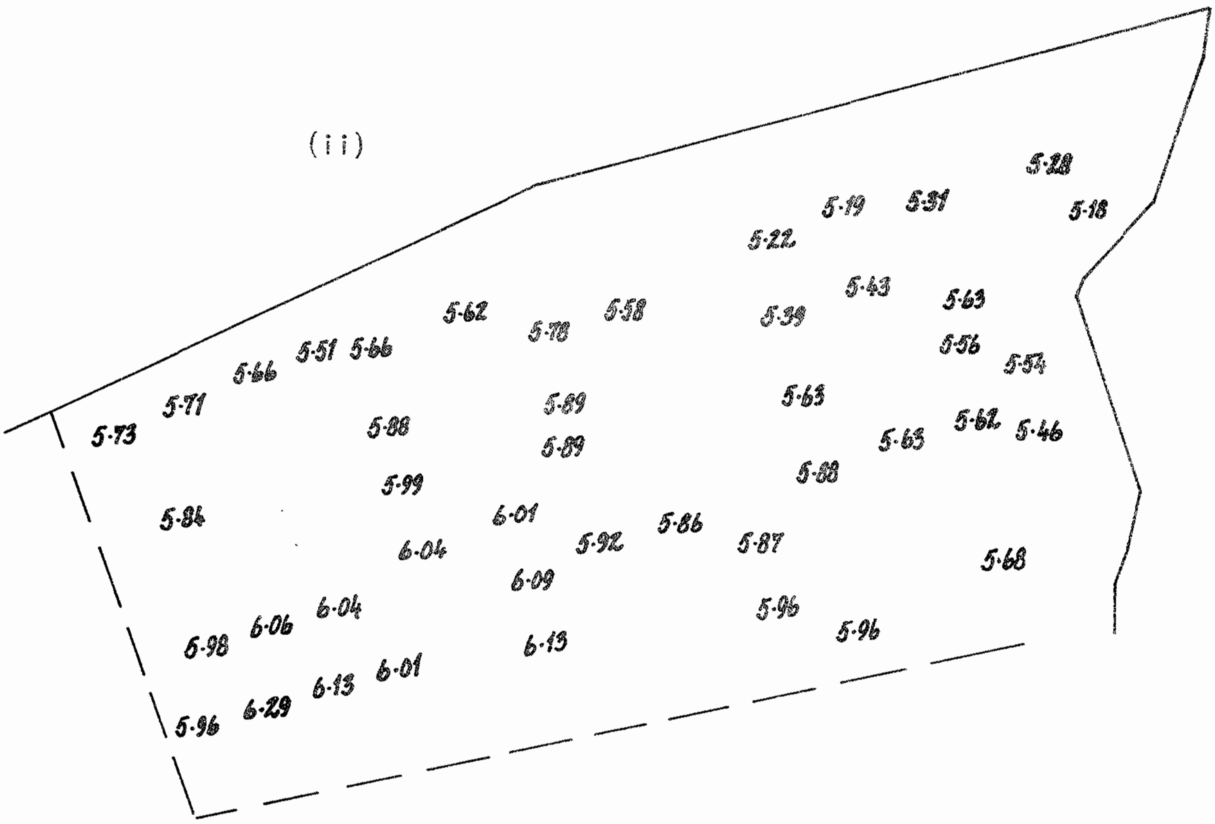


Fig. 9. Levels obtained from (i) 1964 and (ii) 1984 surveys of a part of Norra Myren, showing the continuing loss of elevation. All figures are based on a local fix point.

SUBSIDENCE OF PEAT SOILS

Introduction

The process of peat subsidence after drainage has been described by a large number of authors for a range of climates and conditions (Hallakorpi, 1938; Prytz, 1943; Løddesøl, 1955; Schothorst, 1977).
The causes of subsidence are generally accepted to be:
a) shrinkage of the upper layers due to drying,
b) compaction of the lower layers due to removal of buoyancy and thus increased load,
c) oxidation of organic matter,
d) erosion.

Schothorst (1977) describes how comparison of peat physical properties before and after drainage can be used to determine the relative contribution of each cause to an observed amount of subsidence.
Most authors record a rapid rate of subsidence in the first few years after drainage. Thereafter, the rate slows to a constant level dependent on, for example, climate, peat type, peat thickness, intensity of drainage and cultivation intensity.
Hallakorpi (1938) includes the main factors determining amount of subsidence in the following relationship:

$$S = f(I, B, H, P, W, D, C, M \text{ and } A)$$

where S = subsidence, is a function of I = initial peat thickness, B = botanical composition of peat, H = degree of humification of peat, P = mean precipitation in the area, W = groundwater level and its variations, D = depth of drainage, C = cultivation intensity, M = material mixed with peat during reclamation and A = time factor, years since drainage. Other research work (Stephens and Speir, 1969) suggests that another factor, T = temperature of the soil in that region, should be included.

From available literature on peat subsidence, it is possible to determine the influence of the factors listed above on subsidence amount or rate.
I, initial peat thickness: Subsidence is greater in total quantity and in annual rate where peat is thickest and declines with decreasing thickness of the original peat cover (Stenberg, 1935; Sorteberg, 1973).
B, botanical composition: Osvald (1937) notes that Sphagnum peat subsides less than fen (kärr) peat. Kaitera (1954) found forest peat less susceptible

to subsidence than herbaceous and Stephens & Speir (1969) found that high moor peat subsides more slowly than low moor. Agerberg (1961) summarizes subsidence on a range of Swedish peat types with varying thickness.

H, degree of humification: Highly humified peats subside less than poorly humified peats of the same botanical composition (Osvald, 1937). Decomposed peats have smaller pores and are more dense (Boelter, 1969). German Standards (DIN 1973) indicate that subsidence is related to initial peat density.

P, precipitation: Has already played a part in the former parameters, since it determines peat depth and botanical composition in most peat-forming areas of the world. Peat is formed under conditions where normal bio-degradation of organic matter is prevented, usually by waterlogging (Moore & Bellamy, 1974). As discussed in the previous chapter, climatic change influences the initiation and rate of peat formation (see Fig. 5).

W, watertable and its fluctuations: Generally, the lower the watertable the greater the subsidence. Initial watertable lowering by drainage removes the buoyant force from the upper soil layers and a rapid compaction and surface decline occurs (Hartmark, 1958). Subsequent subsidence due to oxidation of organic matter is directly proportional to watertable depth below the soil surface (Schothorst, 1977).

D, depth of drainage: Subsidence increases with increasing drainage depth and is greatest nearest the drainage canals (Murashko, 1969; Schothorst, 1977; Ilnicki & Burghardt, 1981).

C, cultivation: Ploughed and tilled land is more exposed to oxidation and to erosion and thus subsidence is greater on tilled arable land than, for example, on permanent pasture land (Stenberg, 1935; Agerberg, 1961; Stephens & Speir, 1969; Schothorst, 1977).

M, mineral mix application: Increases load on the lower peat layers and increases subsidence (Lie, 1981).

A, time factor: Is referred to by almost every source cited above. Since subsidence is rapid at first, then decreases to a constant rate, its relation with time is asymptotic (Malm, 1933). Subsidence is cumulative and proceeds as long as peat is exposed to air until all organic matter is oxidised (Sorteberg, 1973).

T, temperature: Influences the rate of biochemical activity and therefore the rate of oxidation. Stephens & Speir (1969) assume that such biochemical activity starts at 5°C and doubles in rate for every 10°C rise in environmental temperature.

Peat subsidence in the Bälinge Mossar area

This report describes the process of peat subsidence in Bälinge Mossar after drainage. Three areas which were surveyed as part of an investigation in 1964 (Göransson & Hellsten, 1964) were chosen for the present study, as more data is available for them. The areas, which are shown in Fig. 10, are:

A. an area of Södra Myren near Oxsätra described by Eriksson, 1912,

B. an area of Norra Myren,

C. an area of Södra Myren near Torvsätra.

As described in the previous section (see Figs 8 & 9) each of these areas was surveyed and mapped in 1898, 1938, 1964 and 1984. Maps (scale 1:4000) show levels referred to local fix points rather than to sea level. Distortion of readings due to land rise above sea level during the 80 year period after drainage is thus avoided.

Further information about each area was available in the form of core sampling records from 1898 and 1938. Position of these sites is shown on the respective drainage maps. Depth of peat and peat type was recorded at each point. In an investigation carried out in November, 1984, all core sampling sites from 1938 which fall within areas A, B and C were sampled again using a core sampler which extracts 50 cm long samples of fixed volume. Type of peat in each layer, thickness of each layer and present land use were recorded for each point. Duplicate samples were extracted from each site and each 50 cm level of peat, packed in plastic and taken to the laboratory for analysis. At a site on each area, samples were taken from 10 cm levels as far down in each profile as the watertable permitted in stainless steel cylinders with diameter 72 mm.

Results from analyses on cylinder samples were used to check the accuracy of core samples. Laboratory analyses and calculations were carried out to determine moisture content relationships, dry bulk densities, density of solids, loss on ignition and pH of all samples. In all, core samples were taken at 16 points on area A, 20 points on area B and 12 points on area C. Where possible full 50 cm samples were taken. Where peat was not sufficiently deep to allow this, the fraction of the sample taken which was peat was retained and the volume adjusted accordingly. At almost all points in areas A and C, present peat thickness (1984) was found to be between 0.5 and 1.0 m. In area B, however, peat was much thicker and 16 points had more than 1.5 m peat. Of these, 6 points had more than 2 m peat. Peat in area B was underlain by a thick layer of pure gyttja but in 1898 and 1938 records, this substance is referred to as 'clay'.

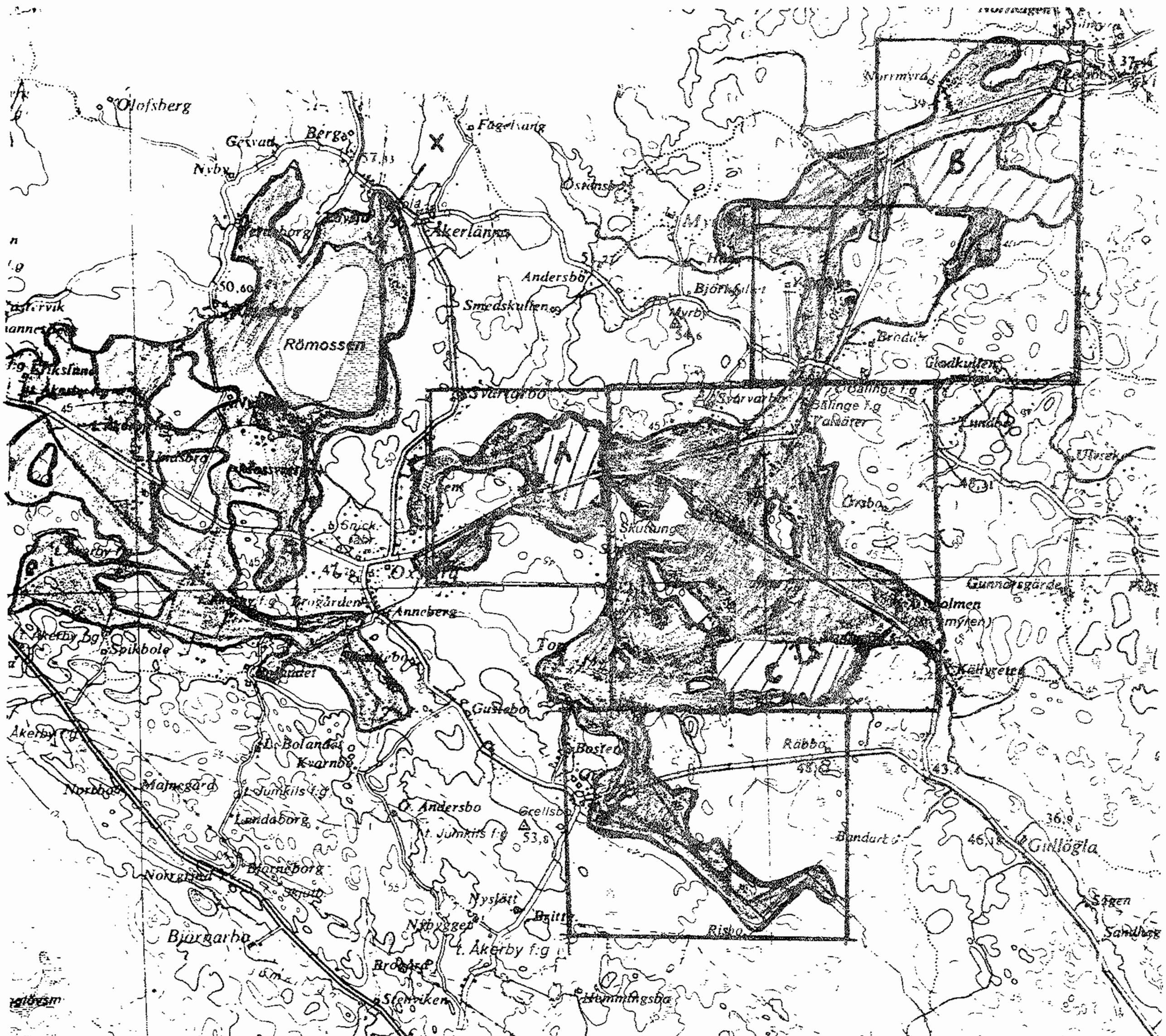


Fig. 10. Map of Bälinge Mossar (shaded area) showing experimental areas A : Södra Myren, B : Norra Myren and C : Torvsätra. Undrained peat samples were taken at the point marked X, to the north of the domed mire.

Scale 1:50,000

Determination of subsidence

The decline in surface levels due to peat subsidence in the 80 years since drainage of Bälinge Mossar was determined by comparing surface elevations from the first survey in 1898 to those from surveys in 1938, 1964 and 1984.
This method involved transferring survey figures from the four surveys for area A, B and C to transparent film and superimposing them on each other. A range of points which coincided in all four surveys could thus be selected and the respective elevations compared. Points were 20 - 50 m apart and, wherever possible, were chosen along arbitrary lines running parallel to or perpendicular to the main drainage canal serving the area. Total decline in surface elevation during the period since initial drainage was calculated for each point. Subsidence in the period between surveys was also calculated and the rate of subsidence (cm/year) compared for the periods.

Core sampling results were compared using the 1938 sites as a starting point. 1984 investigations were carried out on these same sites (5 to 10 m error in location). Since samples were taken from over 6000 sites in 1898, it was possible to find points near the 1938 sites (10 m error in location). As discussed in relation to Table 1, there is a large error in some 1898 measurements. Where possible, points for which exact (to 10 cm) values were recorded were chosen. It should be borne in mind, however, that 1898 values may only be accurate to the nearest metre, and for this reason core sampling results were used only to construct maps showing initial peat thickness in areas A, B and C and to compare subsidence as a function of initial peat depth.
Subsidence values calculated from surface elevations can be expected to be accurate to a few centimetres.

In order to compare physical properties of drained peat with its original properties, it was necessary to obtain samples of undrained peat from a similar profile. The only undrained section of the Bälinge Mossar complex is the domed mire, Åkerlänna Römosse. It is known that the profile of the lagg area is almost identical to the original fen peat profile.(Eriksson, 1912). Samples were taken in triplicate from 10 cm levels throughout the entire peat profile at a point at the edge of the domed mire (Fig. 10). Peat type was recorded and physical properties subsequently determined for each peat type. Thus physical properties of, for example, present day forest peat could be compared to properties of undrained forest peat obtained from the lagg area. It was not possible to obtain an undrained sample of peat formed from the moss Amblystegium, so physical properties of Sphagnum moss peat are used for comparison.

Subsidence in Bälinge Mossar

Results from area A, Södra Myren near Oxsätra.

Fig. 11 shows the layout of the area investigated on Södra Myren. The main drainage canal running alongside the road was first installed in 1840. In 1904, the canals to the east and west (marked X) were installed and in 1938, full field drainage was carried out with open ditches 40 - 80 m apart. The initial peat thickness in the area as detailed in records from 1898 core sampling is shown diagrammatically in Fig. 12. Additional information from Eriksson (1912) and from core sampling in 1938 and 1984 meant that changes in surface levels and peat stratiagraphy in the profile marked (points 1-6) could be shown for a cross-section of the bog (Fig. 13). The Södra Myren area is unique in that it is so well documented before and after drainage.

Actual amounts of subsidence which occurred in area A during the 76 years since initial drainage (1908 - 1984) are shown in Table 2.

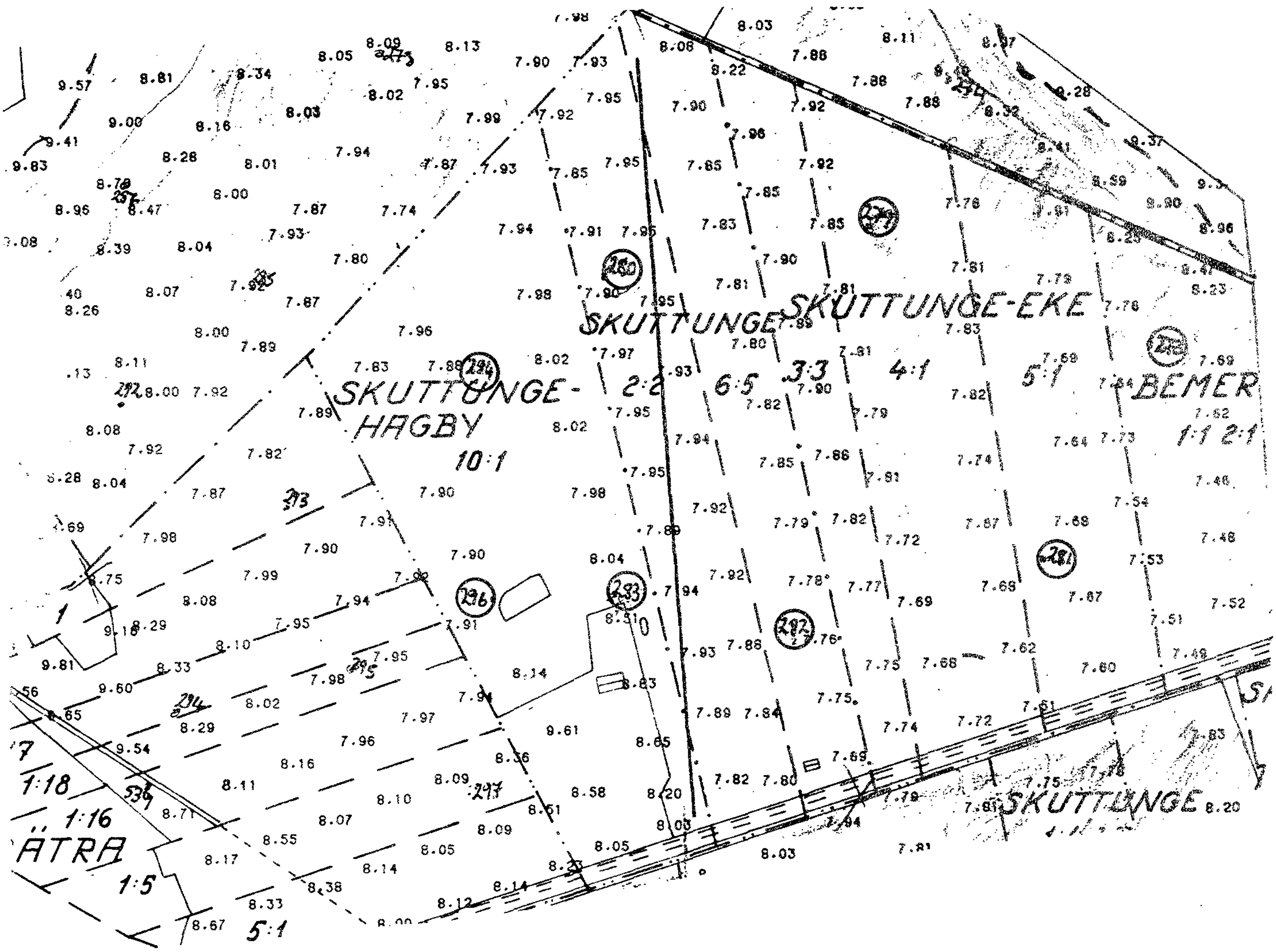


Fig. 11. Area A, Södra Myren, showing levels obtained in the 1984 survey. Core sampling sites (273, 279 etc.) and the Eriksson (1912) profile are also shown.
Scale 1:4000

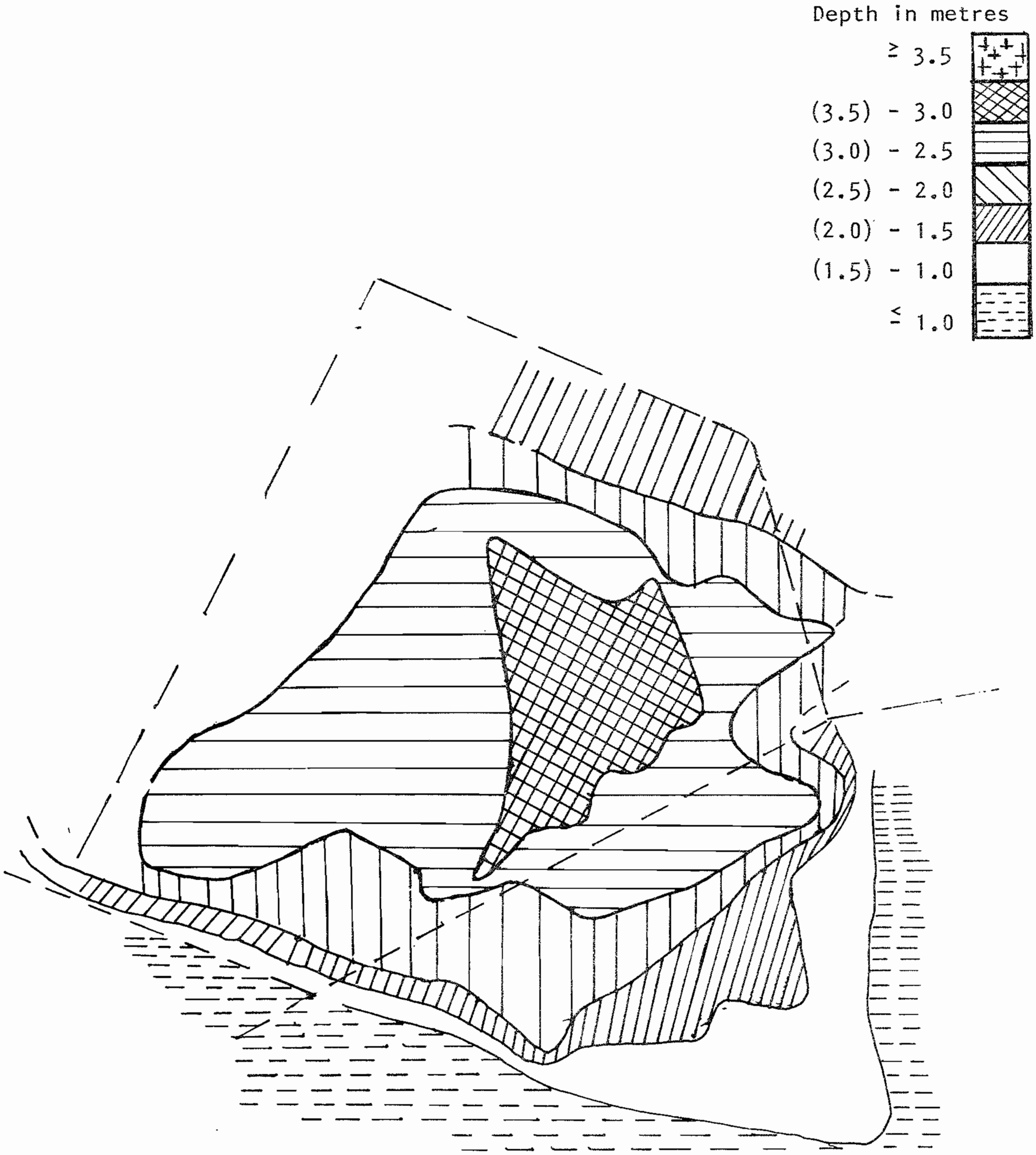


Fig. 12. Map showing original depth of peat in area A, Södra Myren.
Scale 1:6000 (approx)

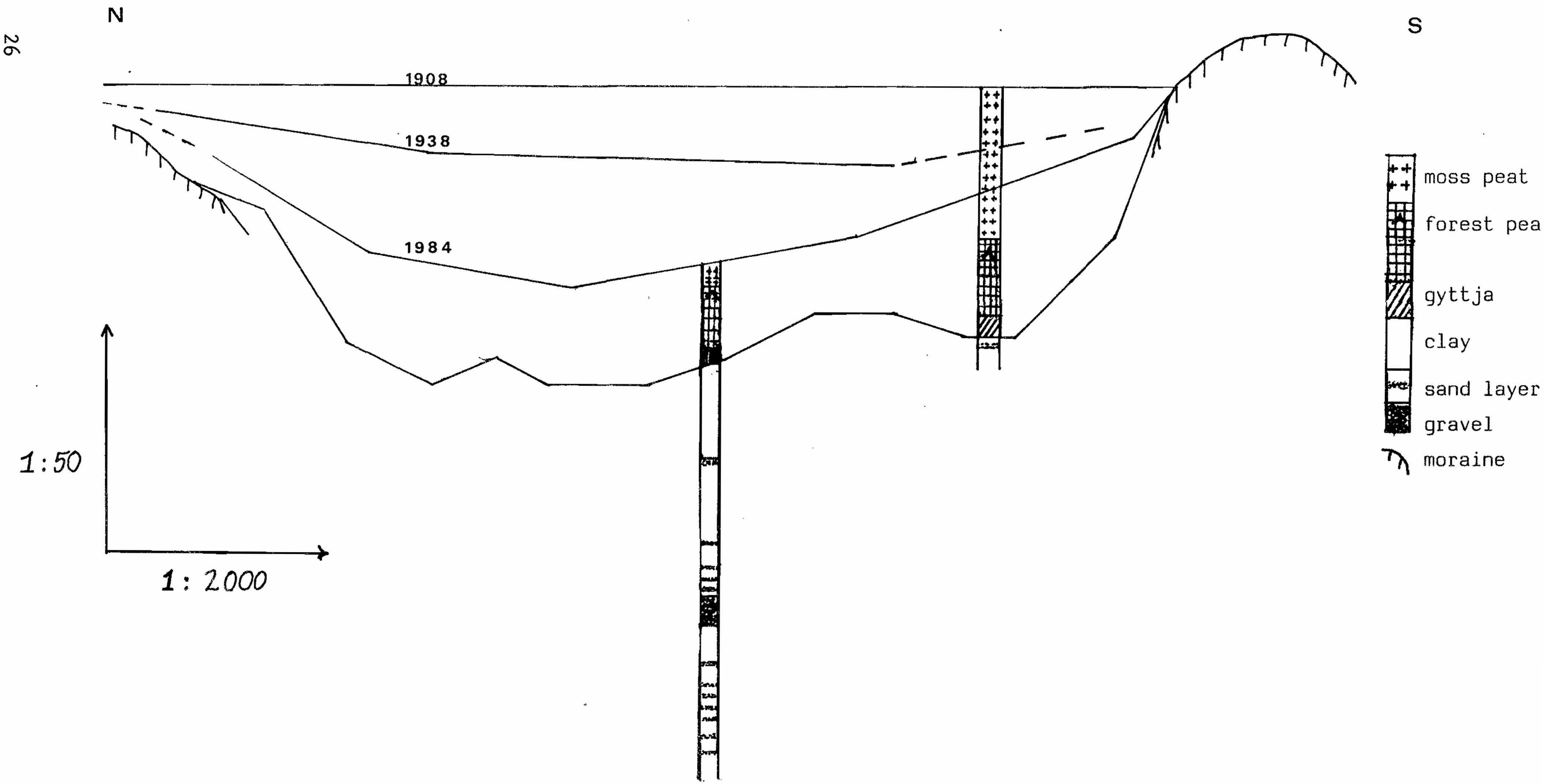


Fig. 13. Section through the profile in Södra Myren investigated by Eriksson (1912) showing surface subsidence and peat strata during the 80 years since drainage.

Subsidence was greatest after initial drainage, with an average of the values given in Table 2 during this 30 year period of 68.3 or 2.27 cm/year. In the last 20 years, 1964 - 1984, subsidence has been on average 37.3 cm or 1.87 cm/year.

Subsidence is related to original depth of peat in Table 3. The thicker the original layer, the greater the subsidence in total and in cm/year. However, when subsidence is expressed as a percentage of original depth, the values obtained show as much variation within a particular thickness class as between classes and is on average lower in the 3.0 m than the 2.5 m peat.

Table 2. Surface subsidence in area A, Södra Myren. Differences in surface levels from surveys in 1898, 1938, 1964 and 1984. Initial drainage took place in 1908.

Point	1908 - 1938		1938 - 1964		1964 - 1984		TOTALS	
	loss (cm)	cm/year	loss (cm)	cm/year	loss (cm)	cm/year	loss (cm)	cm/year
1	67	2.2	38	1.4	45	2.2	150	1.97
2	77	2.6	52	2.0	40	2.0	169	2.22
3	71	2.4	52	2.0	38	1.9	161	2.10
4	73	2.4	43	1.6	42	2.1	158	2.08
5	60	2.0	57	2.2	40	2.0	157	2.06
6	75	2.5	48	1.8	31	1.6	154	2.02
7	70	2.3	47	1.8	36	1.8	153	2.01
8	54	1.8	52	2.0	27	1.4	133	1.75

Table 3. Subsidence as a function of original peat depth Area A, 1908 - 1984.

Point	original depth, m	total subsidence, cm	subsidence, cm/year	subsidence as % of original depth
1	1.8	130	1.71	72.2
2	2.5	200	2.60	80.0
3	2.5	198	2.60	79.2
4	2.5	190	2.50	76.0
5	3.0	210	2.76	70.0
6	3.0	255	3.22	85.0
7	3.0	225	2.96	75.0

Note that the points given in the left column of Tables 2 and 3 do not refer to points on the map - they are simply numbers of individual measurements.

Results from area B, Norra Myren.

The area investigated on Norra Myren was larger than that in the other two areas, and in some places a considerable depth of organic soil remains. Layout of area B is shown in Fig. 14. The main canal running from South to North through the area was the main outlet drain in 1840. The canal running from West to East through the area (marked X) was first installed in 1904 and full field drainage was carried out in 1938. Thus points 37,38,39 lie on an area which has been more intensively drained.

Fig. 15 shows the original depth of peat in the area. Records from 1898 describe material in the profile only as x metres 'torvdy on clay'. A comparison of levels indicates than the gyttja which lies immediately below the peat is classified as clay in 1898 and 1938. This was justifiable in those investigations which had as their aim the agricultural features of the soil and not its classification.

The geography of area B with respect to canals and to peat depth (Figs. 14 & 15) meant that in area B, it was possible to compare subsidence levels along lines of special interest. Thus, line 1 as shown in Fig. 14 runs parallel to the W-E canal. Points on this line are 40-50 m apart, and the last points on this line can be seen to fall within the area of influence of the S-N canal.

Results from comparison of levels along line 1 are given in Table 4. Points 5 and 6 show a lower amount and annual rate of subsidence than other points on the line, which have an average total loss of 150 ± 4 cm. This difference may be due to the proximity of these points to the S-N canal and thus undergoing a higher intensity of drainage. Overall subsidence was greatest in the first 34 year period, with an average of 59 cm or 2.08 cm/year. In the next period after 1938 drainage, subsidence was 46 cm or 1.76 cm/year and in the last 20 years has been 25 cm or 1.1 cm/year.

Table 4. Surface subsidence in area B, Norra Myren. Differences in surface levels from surveys in 1898, 1938, 1964 and 1984. Points lie along a line parallel to the main drainage canal, 60 m from the rim of the drain. Initial drainage took place in 1904.

Point	1904 - 1938		1938 - 1964		1964 - 1984		TOTALS	
	loss (cm)	cm/year	loss (cm)	cm/year	loss (cm)	cm/year	loss (cm)	cm/year
1	52	1.5	59	2.3	36	1.8	147	1.84
2	101	2.9	42	1.6	11	0.5	154	1.92
3	79	2.3	51	1.9	21	1.0	151	1.89
4	89	2.6	41	1.6	19	0.9	149	1.86
5	43	1.3	42	1.6	34	1.7	119	1.49
6	67	1.9	40	1.5	29	1.4	136	1.70

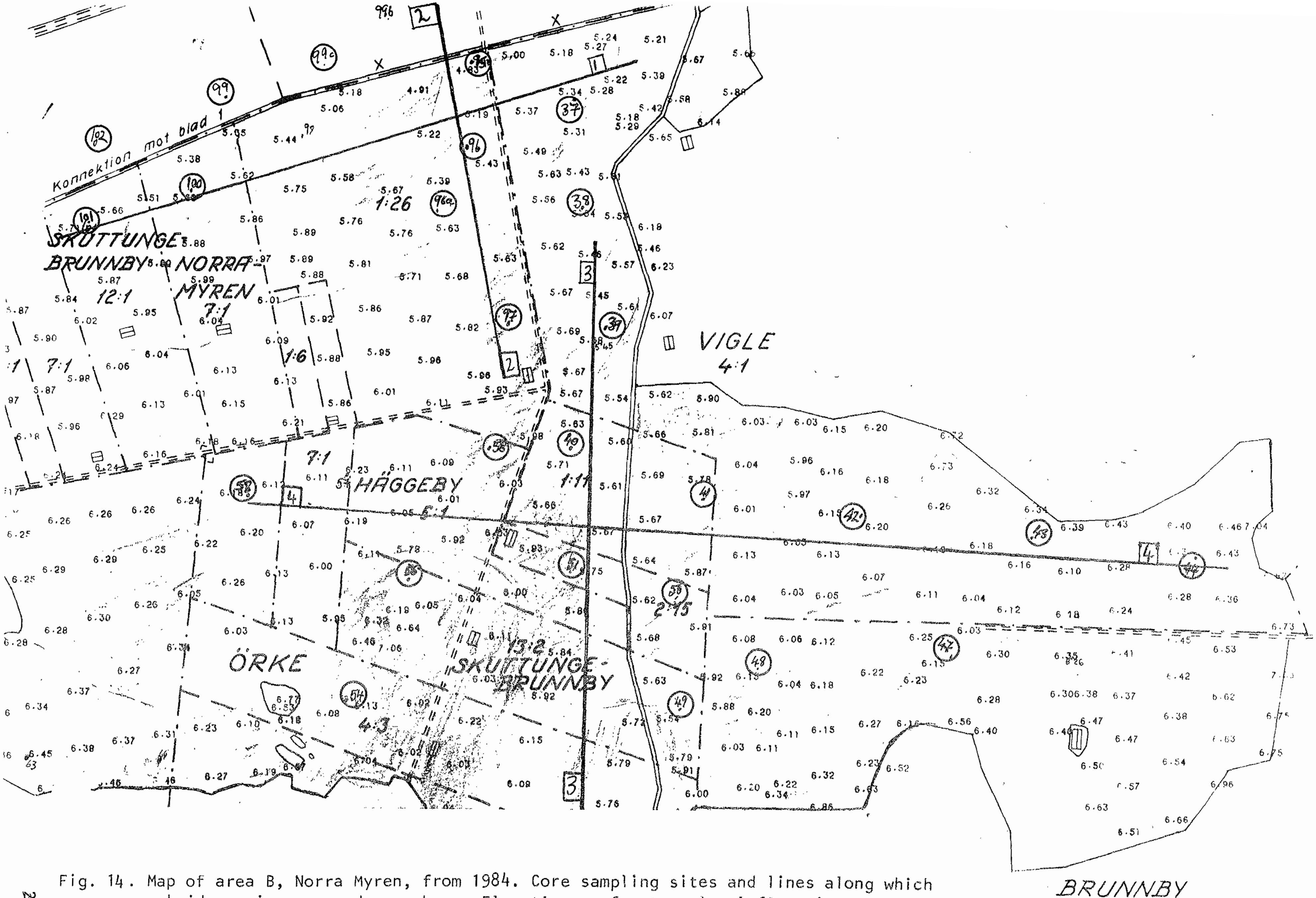


Fig. 14. Map of area B, Norra Myren, from 1984. Core sampling sites and lines along which subsidence is measured are shown. Elevations refer to a local fix point.

Scale 1:4000

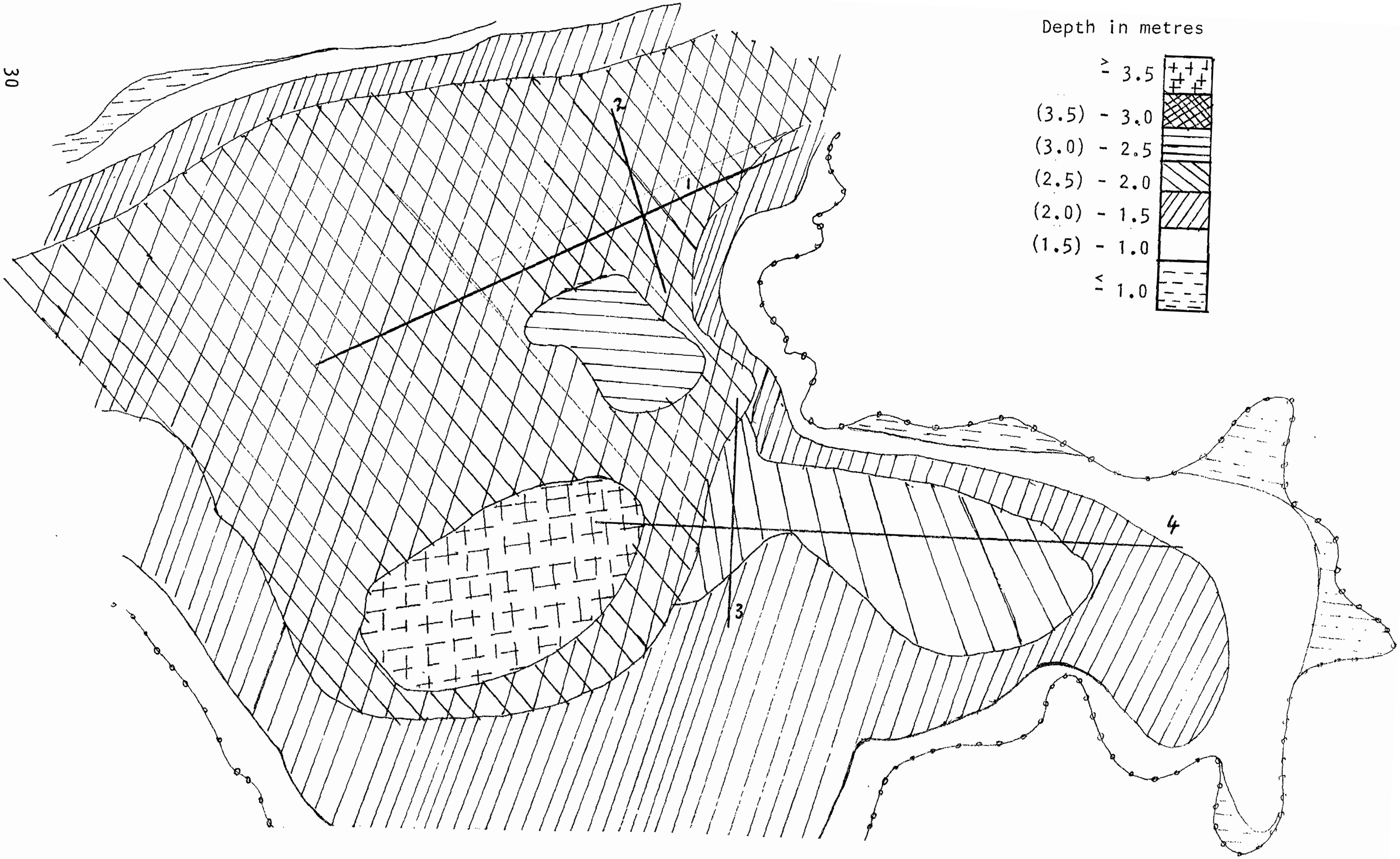


Fig. 15. Map showing original depth of peat in area B, Norra Myren.

Scale 1:6000 (approx)

Line 2, part of which is shown in Fig. 14, extended 100 m above and below the W-E canal and consisted of a series of points 40 - 50 m apart. Results of elevation comparisons are shown in Table 5. Point 3 is on the canal edge and point 4 20 m to the south on the other side of the canal. Again, subsidence was greatest in the first period after initial drainage, when it was on average 82 cm or 2.4 cm/year. Subsidence in the last 20 years was on average 31 cm or 1.55 cm/year. However, since points represent a range of distances from the canal, average values for a particular period of time are, perhaps, distorted.

The point which showed greatest total subsidence was point 3, located on the canal edge. Point 4 showed comparatively low subsidence, assuming that distance from the drain is an important factor. However, points in the immediate vicinity of large canals are subject to error since soil masses extracted during canal dredging and renovation are usually spread on land to one or other side of the canal.

The difference in subsidence rates above and below the canal during the last 20 years (on average 0.76 cm/year above and 2.1 cm/year below) may be due to both drainage and cultivation factors since the former points lay on old, waterlogged permanent pasture and the latter on a reasonably well-drained ploughed cereal growing area.

Table 5. Surface subsidence in area B, Norra Myren. Differences in surface levels from surveys in 1898, 1938, 1964 and 1984. Points lie along a line perpendicular to the drainage canal, which lies between 3 and 4. Initial drainage took place in 1904.

Point	1904 - 1938		1938 - 1964		1964 - 1984		TOTALS	
	loss (cm)	cm/year	loss (cm)	cm/year	loss (cm)	cm/year	loss (cm)	cm/year
1	77	2.3	56	2.1	13	0.6	146	1.83
2	106	3.1	41	1.6	18	0.9	165	2.06
3	107	3.1	51	2.0	17	0.8	175	2.18
4	71	2.1	46	1.8	27	1.3	144	1.80
5	78	2.3	38	1.5	51	2.5	167	2.08
6	75	2.2	28	1.1	50	2.5	153	1.91
7	62	1.8	34	1.3	44	2.2	140	1.75

Line 3 runs parallel to the S-N drainage canal as shown in Fig. 14 and points are 40 - 60 m apart. Table 6 shows the subsidence which occurred at these points. The greatest subsidence was observed in the first period after drainage when it was 60.6 cm or 1.8 cm/year. In the last 20 years, it has been on average 1.8 cm/year but with a great range of values between points.

Table 6. Surface subsidence in area B, Norra Myren. Differences in surface levels from surveys in 1898, 1938, 1964 and 1984. Points lie along a line parallel to the drainage canal first opened in 1840 and re-drained in 1904.

Point	1904 - 1938		1938 - 1964		1964 - 1984		TOTALS	
	loss (cm)	cm/year	loss (cm)	cm/year	loss (cm)	cm/year	Loss (cm)	cm/year
1	95	2.8	18	0.6	44	1.2	137	1.71
2	47	1.4	40	1.5	59	2.9	146	1.88
3	39	1.1	40	1.5	48	2.4	127	1.59
4	36	1.0	36	1.4	42	2.1	114	1.43
5	96	2.8	21	0.8	7	0.3	124	1.55
6	57	1.7	36	1.4	48	2.4	141	1.76
7	54	1.6	40	1.5	29	1.5	123	1.54

Line 4 runs perpendicular to the S-N canal, which lies mid-way between points 4 and 5. Results from this set of points are shown in Table 7. Total subsidence was greatest in the vicinity of the canal (points 3,4,5). Otherwise, no trends could be observed although subsidence was marginally greater (53 cm or 1.59 cm/year) in the period 1904 - 1938 than in the last 20 years (31 cm or 1.57 cm/year)

Table 7. Surface subsidence in area B, Norra Myren. Differences in surface levels from surveys in 1898, 1938, 1964 and 1984. Points lie along a line perpendicular to the drainage canal, which is situated between 4 and 5.

Point	1904 - 1938		1938 - 1964		1964 - 1984		TOTALS	
	loss (cm)	cm/year	loss (cm)	cm/year	loss (cm)	cm/year	loss (cm)	cm/year
1	73	2.1	34	1.3	26	1.3	133	1.66
2	50	1.5	49	1.9	20	1.0	119	1.50
3	59	1.7	36	1.4	58	2.9	153	1.90
4	50	1.5	40	1.5	50	2.5	140	1.75
5	82	2.4	31	1.2	21	1.0	140	1.75
6	39	1.1	35	1.3	33	1.6	107	1.34
7	33	1.0	38	1.5	29	1.4	100	1.25
8	42	1.2	34	1.3	23	1.1	99	1.23
9	51	1.5	28	1.1	25	1.2	140	1.30
10	53	1.5	31	1.2	34	1.7	118	1.50

Results given in Tables 4 - 7 and which are discussed in the preceding text are shown diagrammatically in Fig. 16. The vertical axis shows surface elevation (m) referring to a local fix point and not to sea level.
The scale of the vertical axis is 1:100 and that of the horizontal axis, which shows distance along the surface of the bog, is 1:8000.

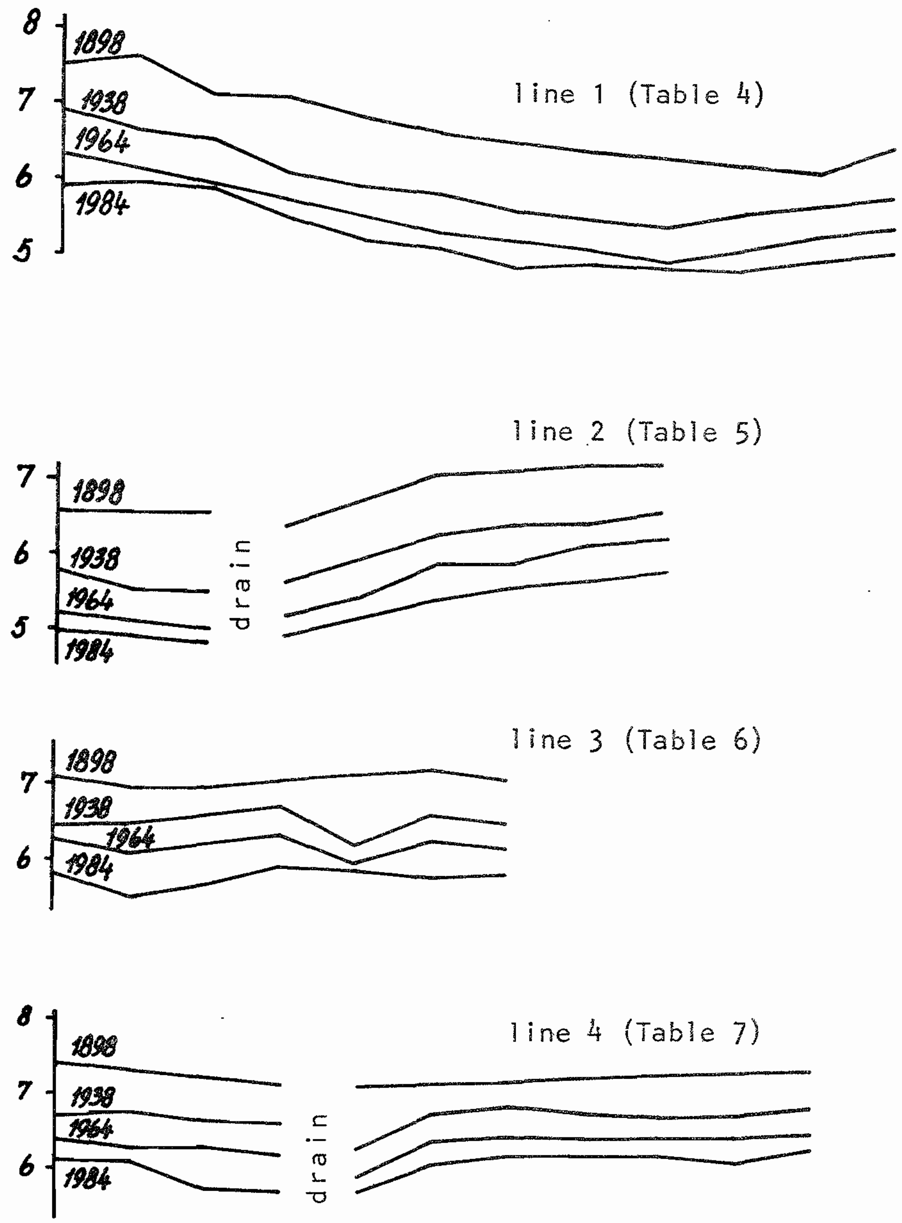


Fig. 16. Changes in surface elevation along lines in area B, Norra Myren. Surface elevation in 1898, 1938, 1964 and 1984 is shown.

Peat subsidence as a function of original peat depth in area B is shown in Table 8. It can be seen that subsidence was greatest in total amount and annual rate in areas where peat was thickest originally. However, when subsidence is expressed as a percentage of original depth this trend is reversed in that an average of values from the 3.5 m class is lower than that of the other two thickness classes in this area.

Table 8. Subsidence as a function of original peat depth
Area B, Norra Myren.

Point	Original depth, m	Total subsidence, cm	Subsidence, cm/year	Subsidence as % of original depth
1	1.5	80	1.00	53.3
2	1.5	120	1.50	80.0
3	1.5	110	1.40	73.3
4	1.5	100	1.25	66.7
5	2.0	160	2.00	80.0
6	2.0	175	2.18	87.5
7	2.0	162	2.02	81.0
8	2.0	155	1.94	77.5
9	3.5	200	2.50	57.1
10	3.5	230	2.90	65.7
11	3.5	250	3.10	71.4

Total subsidence in area B over the last 80 years since initial drainage was, on average, as given below (maxima and minima in parenthesis):

Line	Total subsidence (cm)	Annual rate (cm/year)
1	143 (119 - 154)	1.78 (1.5 - 1.9)
2	155 (140 - 175)	1.94 (1.7 - 2.2)
3	130 (114 - 146)	1.64 (1.4 - 1.8)
4	125 (99 - 153)	1.51 (1.2 - 1.9)

Results from area C, Torvsätra

Fig. 17 shows the area investigated at Torvsätra, area C. This area was not drained before 1908 although a small water course existed where the canal running from west to east now lies. Both main canals (marked X) were installed in the 1908 drainage scheme and field drains 40 - 100 m apart were added in 1938.
Original peat thickness in area C is shown in Fig. 18.

Lines in area C along which levels were compared are shown in Fig. 17. Line 1 compared points parallel to the W-E drainage canal and at a distance of 150 m fron the canal. This line was sited to cover points lying on peat with similar initial thickness and similar drainage intensity.
Line 2 stretched 200 m to each side of the canal running from north to south and thus compared points at a range of distances from the main drain.
A further line was drawn parallel to, and 10 m from, the W-E canal for comparison with Line 1.

Table 9. Surface subsidence in area C, Torvsätra. Differences in surface levels from surveys in 1898, 1938, 1964 and 1984. Points lie along a line parallel to the main drainage canal and 150 m from the rim of the drain. Initial drainage took place in 1908.

Point	1908 - 1938		1938 - 1964		1964 - 1984		TOTALS	
	loss (cm)	cm/year	loss (cm)	cm/year	loss (cm)	cm/year	loss (cm)	cm/year
1	47	1.6	59	2.3	14	0.7	110	1.45
2	37	1.2	58	2.2	22	1.1	117	1.54
3	41	1.4	47	1.8	25	1.2	113	1.49
4	52	1.7	40	1.5	20	1.0	112	1.47
5	43	1.4	52	2.0	27	1.3	122	1.60
6	48	1.6	51	2.0	13	0.6	112	1.47
7	28	0.9	55	2.1	30	1.5	113	1.49
8	32	1.0	51	2.0	34	1.7	117	1.54
9	33	1.1	51	2.0	32	1.6	116	1.53
10	34	1.1	47	1.8	36	1.8	117	1.54
11	33	1.1	47	1.8	38	1.9	119	1.56
12	34	1.1	53	2.0	24	1.2	110	1.45

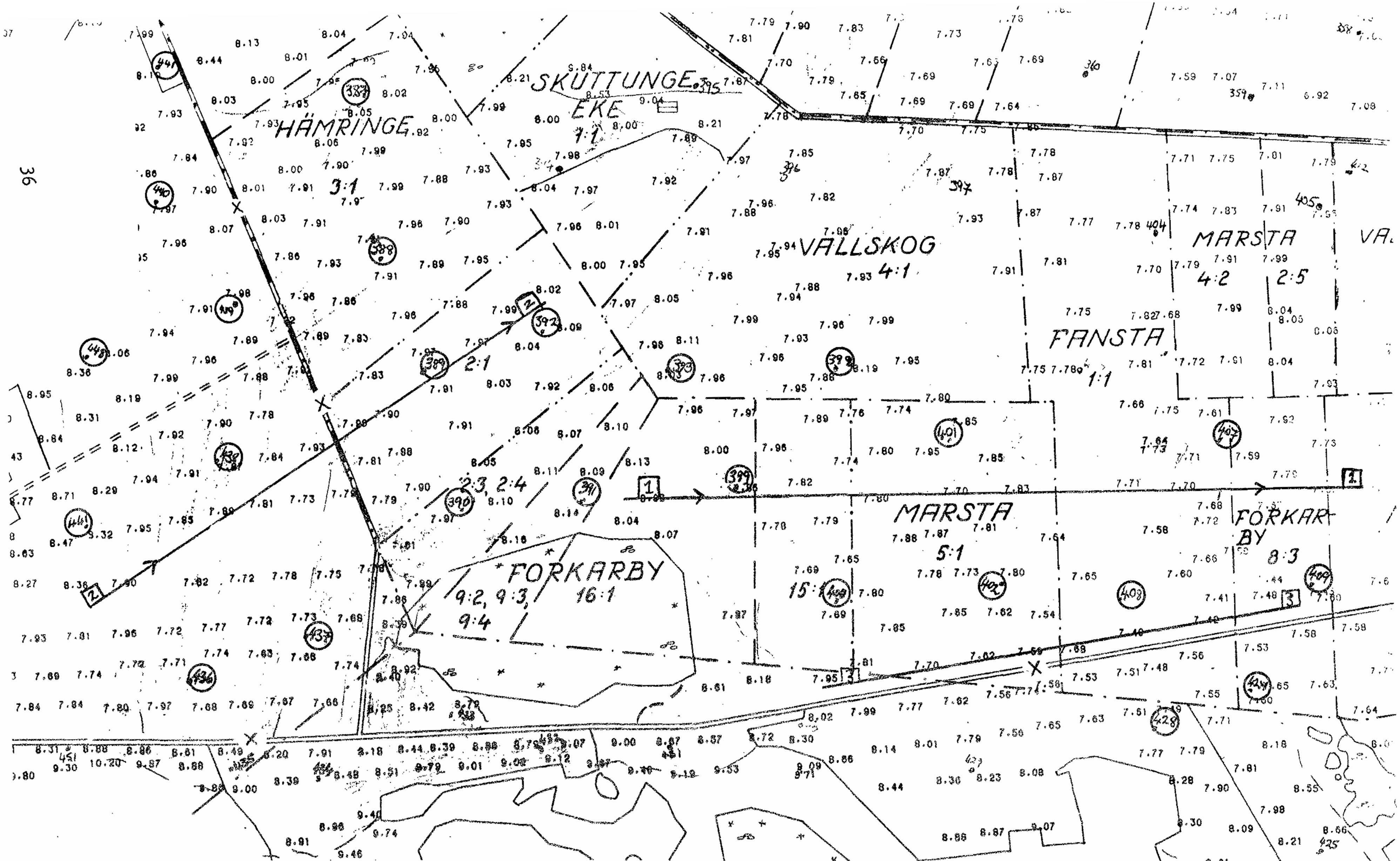


Fig. 17 . Map of area C, Torvsätra, from 1984. Core sampling sites and lines along which subsidence is measured are shown. Elevations refer to a local fix point.

Scale 1:4000

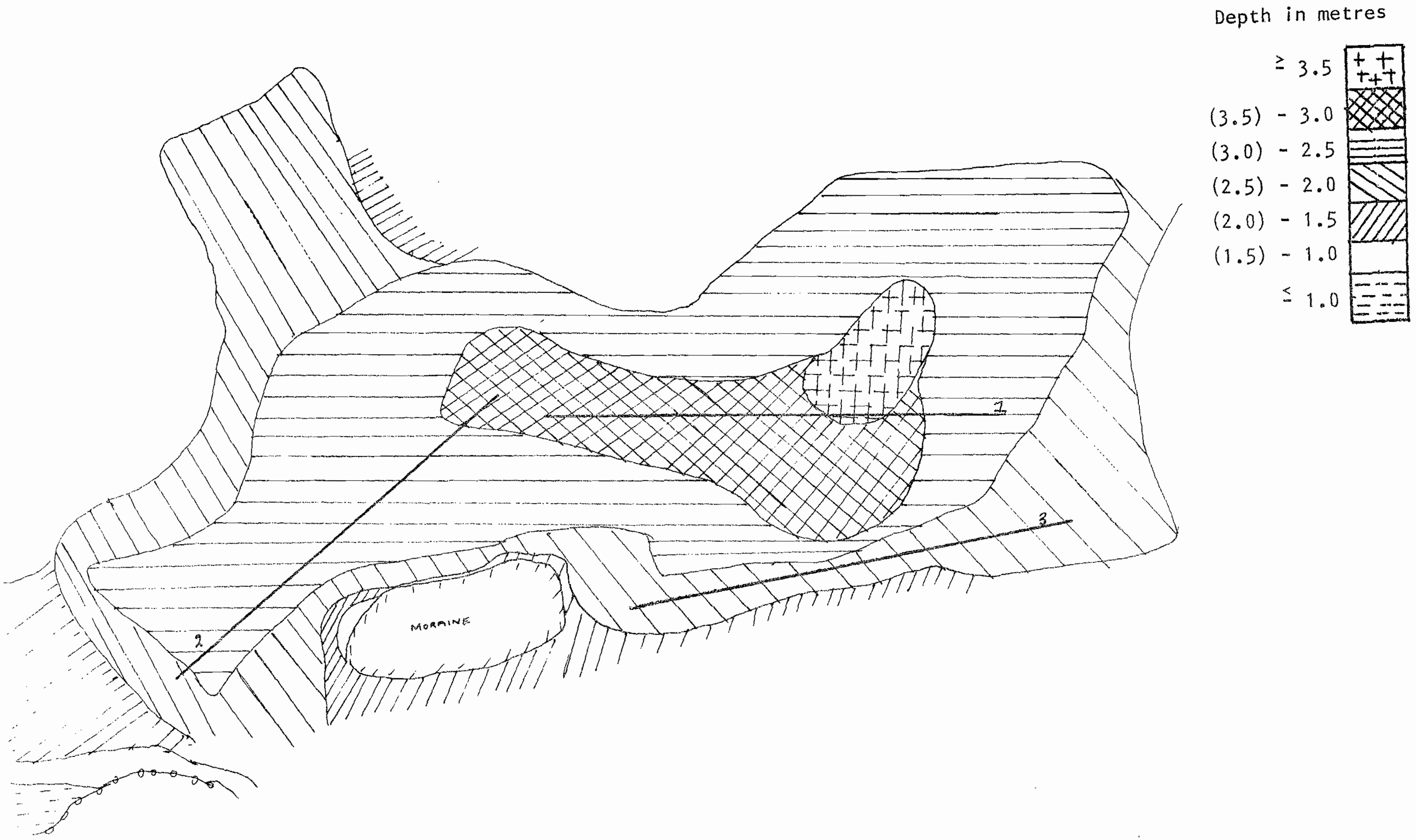


Fig. 18. Map showing original depth of peat in area C, Torvsätra.

Scale 1:6000 (approx.)

Subsidence was greatest, on average, in the period after the 1938 drainage, when it was 50 cm or 1.96 cm/year. In the periods 1908 - 1938 and 1964 - 1984 annual subsidence was 1.26 cm/year and 1.30 cm/year respectively.
Values of subsidence for line 3, parallel to the canal and 10 m from its edge, are shown in Table 10.

Table 10. Surface subsidence in area C, Torvsätra. Differences in surface levels from surveys in 1898, 1938, 1964 and 1984. Points lie along a line parallel to, and 10 m from, the drainage canal.

Point	1908 - 1938		1938 - 1964		1964 - 1984		TOTALS	
	loss (cm)	cm/year	loss (cm)	cm/year	loss (cm)	cm/year	loss (cm)	cm/yr
1	56	1.9	41	1.6	14	0.7	105	1.38
2	44	1.4	41	1.6	30	1.5	115	1.51
3	43	1.4	51	1.9	28	1.4	122	1.60
4	48	1.6	58	2.2	10	0.5	116	1.52
5	59	1.9	49	1.9	26	1.3	134	1.76
6	54	1.8	56	2.1	28	1.4	138	1.81
7	43	1.4	49	1.9	34	1.7	136	1.78
8	55	1.8	40	1.5	40	2.0	135	1.77
9	55	1.8	35	1.3	19	1.0	109	1.43
10	38	1.2	55	2.1	22	1.1	115	1.51

Again, subsidence is greatest after the 1938 drainage, when it was an average 48 cm or 1.81 cm/year. In the last 20 years the rate was 1.28 cm/year, a rate very similar to that obtained for line 1. In the first period 1908 - 1938, the rate was 1.62 cm/year compared to 1.26 cm/year for line 1. This contributed to the difference in total values. However, when comparing lines 1 and 3, differences in original peat thickness (see Fig.17) must be taken into consideration.

Results from points along a line perpendicular to the canal, line 2, are shown in Table 11. The canal is sited mid-way between points 5 and 6 and points are 20 - 40 m apart.

Average subsidence in the period 1908 -1938 was 64 cm or 2.08 cm/year, in the period 1938 - 1964 it was 48 cm or 1.83 cm/year and in the period 1964 - 1984 16 cm or 0.80 cm/year.

Total subsidence was greatest at point 5, near the canal. There was a trend of decreasing subsidence with distance from the canal, assuming that point 1 which lies near the W-E canal, is more intensively drained.

Table 11. Surface subsidence in area C, Torvsätra. Differences in surface levels from surveys in 1898, 1938, 1964 and 1984. Points lie along a line perpendicular to the main drainage canal, which lies between points 5 and 6. Initial drainage took place in 1908.

Point	1908 - 1938 loss (cm)	1908 - 1938 cm/year	1938 - 1964 loss (cm)	1938 - 1964 cm/year	1964 - 1984 loss (cm)	1964 - 1984 cm/year	TOTALS loss (cm)	TOTALS cm/year
1	70	2.3	39	1.5	21	1.0	130	1.71
2	60	2.0	35	1.3	4	0.2	99	1.30
3	67	2.2	39	1.5	20	1.0	126	1.66
4	58	1.6	81	3.1	8	0.4	147	1.93
5	89	2.9	47	1.8	16	0.8	152	2.00
6	70	2.3	53	2.0	16	0.8	139	1.83
7	64	2.1	42	1.6	24	1.2	130	1.71
8	55	1.8	50	1.9	24	1.2	119	1.56
9	52	1.7	41	1.6	19	1.0	112	1.47
10	57	1.9	52	2.0	7	0.3	106	1.39

Subsidence as a function of original peat depth is shown in Table 12. Again, total subsidence increased in total amount and annual rate with original peat thickness. However, subsidence as a percentage of original peat depth varied as much within a particular thickness class as between classes

Table 12. Subsidence as a function of original peat thickness Area C, Torvsätra.

Point	Original depth, m	Total subsidence, cm	Subsidence cm/year	Subsidence as % of original peat depth
1	2.0	152	1.99	76.0
2	2.0	149	1.96	74.6
3	2.0	157	2.07	78.5
4	2.5	215	2.83	86.0
5	2.5	180	2.37	72.0
6	2.5	185	2.43	74.0
7	2.5	197	2.58	78.8
8	3.0	212	2.79	70.7
9	3.0	210	2.76	70.0
10	3.0	230	3.03	76.6
11	3.5	275	3.62	78.5
12	4.0	324	4.26	81.0

Results given in Tables 9 - 11 and which are discussed in the preceding text are shown diagrammatically in Fig. 19. The vertical axis shows surface elevation (m) referring to a local fix point and not to sea level.
The scale of the vertical axis is 1:100 and that of the horizontal axis, which shows distance along the surface of the bog, is approximately 1:8000.

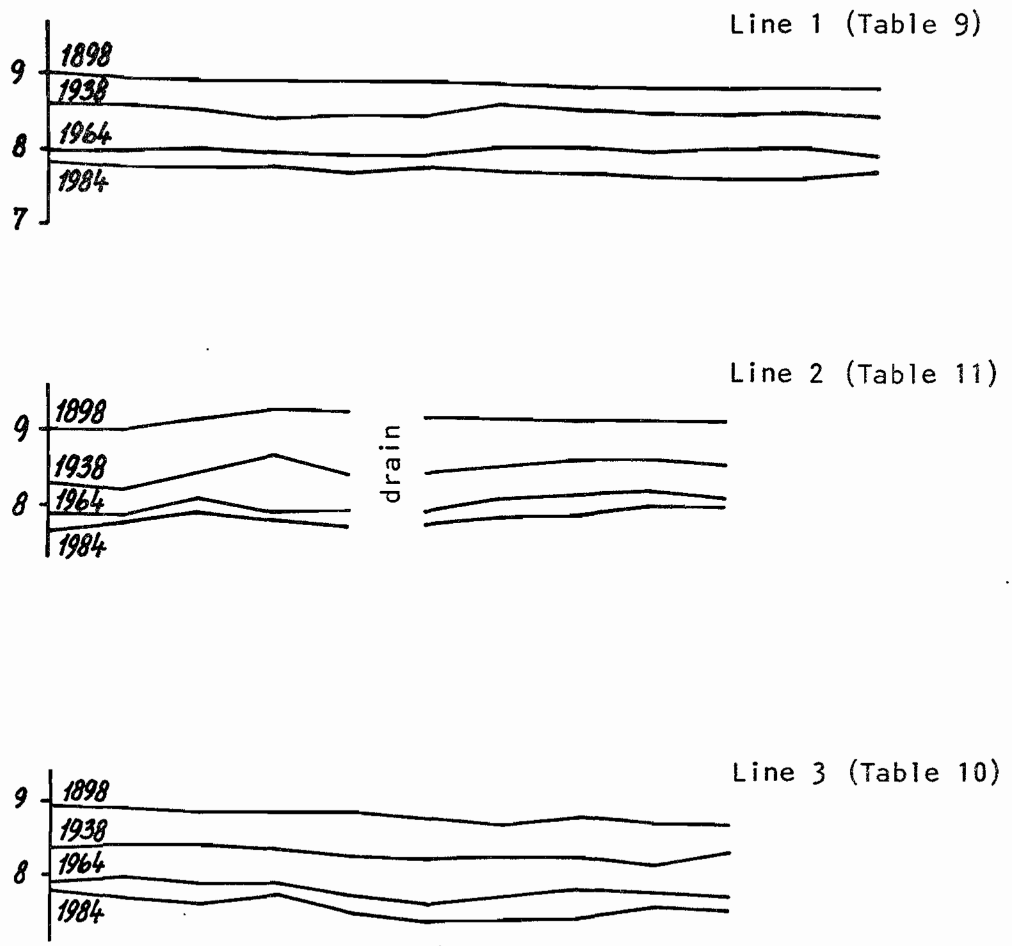


Fig. 19. Changes in the surface elevation along lines in area C, Torvsätra.
Surface elevation in 1898, 1938, 1964 and 1984 is shown.

Total subsidence over the 76 years since drainage in area C was, on average, as shown below (maxima and minima in parenthesis):

Line	Total subsidence (cm)	Annual rate (cm/year)
1	115 (110 - 122)	1.51 (1.4 - 1.6)
2	122 (105 - 138)	1.61 (1.4 - 1.8)
3	125 (99 - 152)	1.66 (1.3 - 2.0)

Fig. 20 combines the data given in the previous pages in graph form. Subsidence (cm) during the period 1900 - 1984 is shown for each of the three areas investigated and for a range of peat thicknesses. For all points, an average of all values available was used.

The trend of increasing subsidence with depth of peat is clearly shown in Fig. 20.

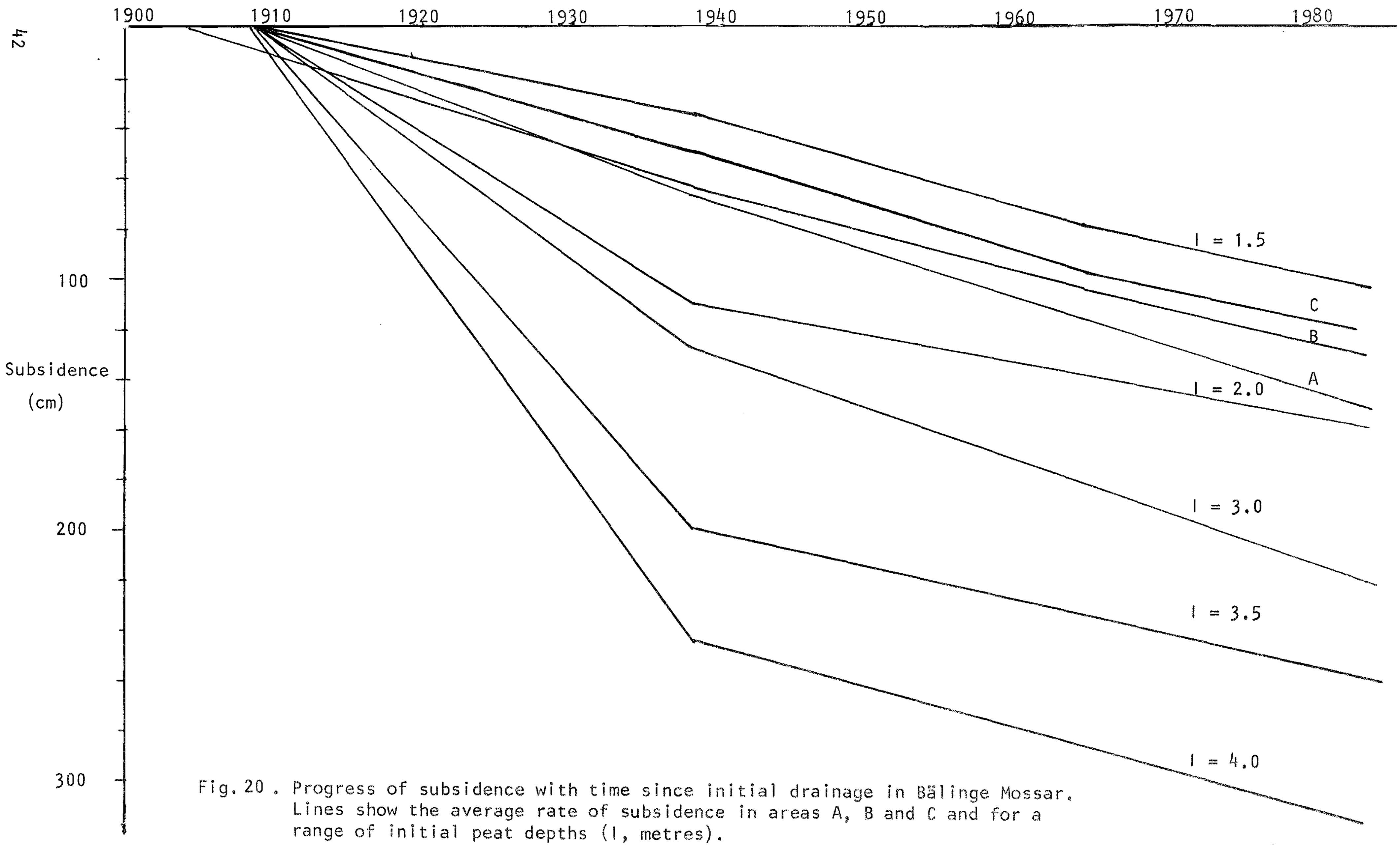


Fig. 20 . Progress of subsidence with time since initial drainage in Bälinge Mossar. Lines show the average rate of subsidence in areas A, B and C and for a range of initial peat depths (I, metres).

EFFECT OF CULTIVATION ON SUBSIDENCE RATE

Introduction

As has been mentioned previously, intensity of cultivation has an influence on the rate of subsidence of a peat soil. This is partly due to increased oxidation which occurs when the soil is left open to the elements, especially at times of the year when the temperature is higher than 5°C. Subsidence may also be partly due to the compacting effect exerted by heavy machinery or even grazing animals. According to Stenberg (1935), all farming operations involving passage of machinery or disturbance of the peat increase the rate of subsidence of that peat.

It is difficult to isolate the effects of cultivation intensity from those of other factors such as initial peat depth or distance from the drainage canal (Agerberg, 1961). In order to isolate the effects of cultivation, comparisons can be made between points where initial peat thickness was similar and where points lie along a line parallel to, and equidistant from, a main drainage canal.

A problem with relating land use to subsidence rate in Bälinge Mossar is the structure of farming in that area. Öhman (1966), who discusses farm ownership and farm structure in the Bälinge Mossar area from an economist's point of view, notes that the area is divided up into a large number of small parcels of land with different owners. Furthermore, much of the land belongs to farms which lie more than 3 km from the area. From the point of view of the present investigation, this means that points along an arbitrary line can fall on a number of different properties. Land use may have been very different on all these strips, depending on the type of farm to which they belong. Öhman (1966) describes both animal-based and arable farms in this area. Land belonging to the former is most likely to have been used for grass production or grazing, while that belonging to the latter was probably used for intensive cereal production.

Subsidence and land use in Bälinge Mossar

In order to avoid the effects of drainage on subsidence rate, it was decided to investigate land use and its relationship to subsidence in the period 1964 - 1984. It can be assumed that no drainage of the main canals has taken place during this period, or in fact since the 1940's. Dredging of these canals has been so intense, however, that the watertable may have been lowered somewhat in recent years.

With the help of farmers in the area, it was possible to determine approximately the use to which the land within areas A, B and C has been put in the last 20 years. Due to changes in tenancy and to the large number of individual properties which fall within these investigation areas, it was not possible to obtain first-hand information for every field.

Area A

Points along which subsidence was measured in area A lie along a line parallel to Eriksson's (1912) profile as shown in Fig. 11, and points fall on a range of initial peat thicknesses (see Figs. 12, 13). Points 1-8 also lie at decreasing distance from the main drainage canal. The cultivation pattern on the particular field where these points lie has been 5-10 years of a grass ley from which one cut of hay is taken per year and the aftergrass grazed. When the ley deteriorated (5-10 years) it was ploughed in and the land was allowed to lie fallow for 1 or 2 years, depending on weather conditions. As can be expected, subsidence under this system was high. As shown in Table 2 (Chapter 2), the annual rate of subsidence in the period 1964 - 1984 has been an average of 1.9 cm/year.

Area B

Points along line 1, area B, lie on peat which had similar initial thickness (see Fig. 15) and points 1-4 lie at an equal distance from the drain. The land on which points 1-4 lie has been under an old grass ley for 18 of the last 20 years but has recently been drained and ploughed. Subsidence rate (see Table 4) was on average 1 cm/year during the period 1964 - 1984. Points on line 2 lie on similar original peat depth but at varying distance from the drain. Points 1-3 lie on the same field as points 1-4 on line 1. Points 4-7 on line 2 lie on a plot which has had 4 years grass, 1 year barley for the last 10 years and which had almost continuous cereals in the period 1964 - 1974. Subsidence rate (Table 5) has been 2.1 cm/year during these 20 years.

Points on line 3 have different initial peat thickness values but lie at an equal distance from the drain. Land at points 1-3 has been used for intensive cereal production and points 4-7 lie on individual strips of land which have had a range of uses including permanent pasture and 50:50 cereal/grass production. Subsidence rate, as shown in Table 6, has varied widely with an average for points 1-3 of 2.1 cm/year.

Points on line 4 have both different initial thickness and distance from the drain. Points 4-10 lie on the same property as points 1-3 on line 3 and the average rate of subsidence for points 4-10 was 1.5 cm/year in the last 20 years (Table 7).

Area C

All points on line 1 lie at an equal distance from the main drainage canal and on peat with similar initial thickness (see Fig. 18). Points 1-6 lie on land which had an old grass ley 1964 - 1974 and which since then has had a rotation of 4-5 years grass and one year of barley. Points 7-11 lie on land which has had a rotation of 4 years grass, one year cereal or green forage crop for the 20 year period. From Table 9 it can be seen that the rate of subsidence for points 1-6 was 0.98 cm/year in the period 1964 - 1984 whereas for points 7-11 the average rate was 1.7 cm/year.
Points on line 2 in area C lie on an area where original peat thickness was 1.5 - 3.0 m and where distance to the drain also varies. Points 6-10 lie on a field which has lain under grass and been cut for hay or grazed for most of the last 20 years. A rotation of 1 year cereal, 3-4 years grass was begun about five years ago. Subsidence rate in the period 1964 - 1984 is shown in Table 11. Neglecting point 10, which lies very near a moraine outcrop, the average rate of subsidence for points 1-9 was 1 cm/year.

Summary of results

Results described in the previous paragraphs are summarized according to three factors: I = initial peat thickness (m), D = distance from the drain (m) and C = cultivation pattern (ratio, years). S = subsidence rate, average value and range in the period 1964 - 1984 (cm/year).

Area	I	D	C	S
A	2.5	50 - 500	5:1 grass/open fallow	1.9 (1.4-2.2)
B	3.0	60	old grass ley	1.0
B	3.0	1 - 100	"	0.8 (0.6-0.9)
B	3.0	1 - 100	1:1 cereal/grass	2.1 (1.3-2.5)
B	1.5 - 3.0	40	mainly cereal	2.1 (1.2-2.9)
B	1.5 - 3.0	40	range of land uses	- (0.3-2.4)
B	1.0 - 3.5	1 - 600	mainly cereal	1.5 (1.0-2.5)
C	3.0	150	4:1 grass/cereal	1.7 (1.5-1.9)
C	3.0	150	8:1 grass/cereal	0.9 (0.6-1.3)
C	2.0	10	4:1 grass/cereal	1.3 (0.5-2.0)
C	1.0 - 3.0	1 - 200	old grass ley	1.0 (0.8-1.2)

CHANGES IN PHYSICAL PROPERTIES OF PEAT AFTER DRAINAGE

Changes in physical properties of peat brought about by drainage are:

- increased bulk density
- decreased porosity
- increased ash content

(Stephens & Speir, 1969; Schothorst, 1977 and 1982; Ilnicki & Burghardt, 1981). The change in bulk density and porosity is due to peat solids settling due to removal of water and to subsequent increased load on the layers below the water-table. Particles are also broken down and a tighter packing formation is formed. Increased ash content is a result of disappearance of organic matter as peat exposed to air by drainage is broken down by microbiological processes. The actual amount of mineral substances present remains the same but forms a greater proportion of the total after oxidation.

By comparing physical properties of peat before and after drainage, it is possible to calculate how much of an observed subsidence is due to a particular cause (Schothorst, 1977).

Laboratory Analyses

Moisture content at sampling was obtained by weighing samples on return to the laboratory. Since volume of both cylinder and core samples are known and since peat was saturated in many cases, bulk densities at sampling and at saturation could be calculated. Dry bulk density was obtained by drying samples under vacuum at 55°C for 72 hours.

Density of solids was measured on air-dried samples of peat for which moisture contents were determined simultaneously.

Loss on ignition was determined on vacuum-dried samples by incineration at 500°C for 6 hours.

In addition, shrinkage (volume %) was determined after drying of cylinder samples and pH was measured for a range of core samples.

These analyses were carried out on samples from the three areas investigated and on samples of undrained peat from Römossen.

Physical properties of undrained peat from Bälinge Mossar

Samples were extracted from the edge of the domed mire. Vegetation at this point consisted of occasional birch and fir trees with tussocks of matgrass and a Sphagnum cover.

The profile consisted of an upper layer of rather poorly humified Sphagnum peat 35 cm thick, below which was a layer of forest peat which was very wet. The forest peat was black above, changing to reddish (indicating presence of Alnus remains) below 80 cm..A gradual changeover to fen peat occurred at 90-95 cm. Within the fen peat, various layers could be distinguished: remains from bush and tree vegetation, a layer of Carex peat and below, Equisetum remains. Just above the gyttja was a 20 cm layer of Phragmites peat. Gyttja, yellowish-green at first, began at 220 cm below the surface and continued down to 630 cm, with a change to a darker green at 250 cm. Below 550 cm, the colour changed again, to light green, and shell remains were found in layers 4 cm apart. A sand layer occurred at 630 cm, than a change from gyttja to blue clay.

A summary of physical properties of peat from different layers in this profile is given in Table 13 and more complete results from analyses in the Appendix.

Table 13. Physical properties of undrained peat from Römossen and of the underlying gyttja and clay layers.

Classification	Bulk density, g/cm^3		Density of solids, g/cm^3	Loss on ignition, %	Porosity (vol.%)
	Saturated	Dry			
Sphagnum	1.07	0.17	1.45	93.3	88.2
Forest peat	1.13	0.19	1.48	88.6	87.2
Fen - leaf	1.14	0.17	1.45	89.5	88.2
- Carex		0.14	1.42	91.4	90.1
- Equisetum		0.17	1.50	92.8	88.7
Phragmites	1.08	0.13	2.10	88.5	94.0
Gyttja	1.27	0.27	2.10	24.0	87.1
Clay	1.46	1.09	2.60	14.0	58.1

No sample of undrained dy was obtainable from this profile, so it was necessary to use values from points in area B which had 2 m or more of peat remaining and to adapt these values to allow for any compaction which may have taken place.

Physical properties of drained peat from Bälinge Mossar

Results of all analyses carried out on samples taken from areas A, B and C are given in Appendices. Core sampling sites are referred to by the numbers given them in the 1938 investigation. Position of these points can be seen in Figs. 11, 14 and 17. A summary of results showing average values for each area is given in Table 14. All points in the area are included in each average, regardless of modifying factors.

Table 14. Summary of physical properties of drained peat in Bälinge Mossar, average of all points in each area investigated.

Area	Level (cm)	Bulk density, saturated (g/cm^3)	Bulk density dry (g/cm^3)	Density of solids (g/cm^3)	Loss on ignition (%)	pH	Porosity (vol.%)
A	0-50	1.07	0.24	1.66	80.3	5.7	85.5
	50-100	1.18	0.21	1.58	87.0	5.4	86.1
B	0-50	1.08	0.24	1.56	83.6	5.5	83.3
	50-100	1.14	0.18	1.50	88.4	5.4	87.8
	100-150	1.12	0.14	1.49	86.3	5.4	90.7
	150-200	1.09	0.13	1.48	79.9	5.8	91.0
C	0-50	1.08	0.25	1.62	81.7	5.7	84.8

Decrease in volume of peat samples after drying is shown in Table 15. Samples are extracted in cylinders of known volume, dried at 55°C under vacuum and their diameter and height measured (Andersson, 1955)

Table 15. Shrinkage in volume (E_v, vol.%) of peat samples from areas A,B and C.

Level, cm	A	B	C
0 - 10	65	65	66
10 - 20	71	66	70
20 - 30	76	69	73
30 - 40	77	79	74
40 - 50	79	79	77

Description of profiles in the drained areas investigated

Area A

Peat depth in this area was, on average, 57 cm with a range of values from 20 to 110 cm. The profile at most points consisted of an upper 20 - 35 cm of dense, well-humified peat on 10 - 30 cm of forest peat on a 2 - 10 cm layer of dy. The profile below the peat consisted of clay, which was more than 5 m deep at a short distance from a moraine outcrop. The clay was blue-grey in colour in its upper layers, fresh light blue below. A sand layer 2 cm thick occurred at 170 cm below the soil surface and banded clay made up the profile below this depth. A layer of coarse gravel and sand 20 cm thick occurred at 320 cm below the surface and could be mistaken for fast bottom. Banded clay continued below this.

Area B

This area did not have a single typical profile but two main types could be distinguished. Points along the perimeter of the area, east of the main S-N drainage canal, were in general shallow and peat at these points rested on clay. At points 39 - 49 (see Fig. 14) the profile consisted of 25 - 40 cm peat on clay. The peat was dark and well-humified and plant remains could not be distinguished, at least above plough depth. At some points forest peat remains could be identified below 30 cm depth.

At all other sampling points in the area, peat depth was much greater, 1 - 2 m. The profile here consisted of 20 - 50 cm dark, well-humified peat on 50 - 100 cm forest peat on a 5 - 15 cm layer of dy. The peat layers at these points were underlain by a thick deposit of gyttja. At approximately 350 cm under the surface, this gyttja gave way to banded clay.

Area C

In this area, peat depth was on average 67 cm, with a range from 20 - 98 cm. The profile was similar to that at area A, consisting of 20 - 40 cm well-humified peat on 10 - 30 cm forest peat on 5 cm dy. The peat was underlain by clay.

Field Conditions

Surface condition and present land use varied from one owner's property to the next. Many fields were ploughed or had traces of ploughing in their profile. Tree stumps and branches piled up at the edge of fields were evidence that the upper moss peat layer had compacted and disappeared and that forest peat was reached by the plough. While forest peat is normally supported by its woody inclusions so that it is less susceptible to subsidence than herbaceous peat (Kaitera, 1954), when stumps and branches are removed there is an immediate and rapid surface subsidence. The peat material remaining after stump removal coll-

-apses to fill the spaces in the profile which can have a considerable volume. Groundwater levels were observed during removal of cylinder samples. In areas A and B, the groundwater level was at around 50 - 60 cm below the surface in November, 1984. In area C, water ran horizontally in the 40 - 50 cm layer but below this there was no water movement and though the peat was fully saturated, it was firm enough to allow cylinder sampling down to 1 m depth.

Effect of drainage on physical properties of peat

The influence of drainage on the physical properties of peat can be seen by comparing results for forest peat, since it is easily identifiable in the profile. Bulk density of undrained forest peat was 0.19 g/cm^3 (see Table 13) and this increased to an average of 0.24 g/cm^3 in drained peat (see Table 14). The profile in area B is sufficiently deep to allow comparison of successive 50 cm levels. Bulk densities from 50 cm levels at points where peat is deepest in area B are shown in Table 16.

Table 15. Dry bulk density (g/cm^3) of peat from 50cm layers at points in area B where remaining peat thickness is more than 2.0 m.

Level	Point 98	99	99a	99c	100
0 - 50	0.25	0.21	0.23	0.26	0.25
50 - 100	0.18	0.19	0.14	0.16	0.19
100 - 150	0.13	0.15	0.12	0.13	0.15
150 - 200	0.12	0.16	0.10	0.12	0.16

These results show a range of values in any one layer but a general trend of decreasing bulk density with distance from the soil surface. Properties of the upper 50 cm layer are most affected by drainage an observation which agrees with results from Schothorst (1977).

Data on saturated bulk density are only available for the undrained profile and for layers under the watertable, i.e. the 50 - 100 layer and below. Results where available are shown in appendices to this chapter.
Values for porosity as shown in appendices are calculated from dry bulk density and density of solids for each sample as follows (after Andersson, 1955):

$$\text{Porosity (vol.\%)} = \left(1 - \frac{\text{dry bulk density}}{\text{density of solids}}\right)$$

Porosity of undrained peat was between 87 and 94 vol.% (see Table 13 and Appendix 1) and that of the upper 50 cm of drained peat ranged from 83.3 to 85.5 vol.% (see Table 14). Porosity of the lower layers in area B was between 88 and 91%.

Loss on ignition is a measure of the organic matter content of the peat. In this investigation, values for undrained peat ranged from 88 - 93 % compared to values for drained peat (upper 50 cm) of 80 - 84 %. The 150 - 200 cm layer in area B (see Table 14) and the lowest layer of peat at other sampling points (see appendices) show a lower organic matter content than the layers above due to the inclusion of gyttja or clay material from the underlying layer in the core sample. In many cases, it was difficult to distinguish where the peat ended and the under layer began.

PREDICTING SUBSIDENCE

Formula for the prediction of subsidence

Formulae from the following sources are described with their particular applications and limitations:

Hallakorpi (1938)
Ostromecki (1956)
Segeberg (1960)
Terzaghi & Peck (1956)
Svadkovsky (1939)
Murashko (1969)
van der Molen (1975)
Schothorst (1982)
Stephens & Stewart (1977)

Hallakorpi (1938) produced a formula based on existing subsidence data of the form : $S = a\ (0.08T + 0.066)$ where S = subsidence in m, T = thickness of the original layer in m and a is a coefficient based on the volume of solids of the peat thus:

Solids (vol.%)	Condition	Factor 'a'	Formula
more than 12	dense	1.000	$S = 0.08T + 0.07$
7.5 - 12	rather dense	1.375	$S = 0.11T + 0.10$
5.0 - 7.4	rather loose	2.000	$S = 0.16T + 0.13$
3.0 - 4.9	loose	2.875	$S = 0.23T + 0.18$
less than 3	very loose	4.000	$S = 0.32T + 0.26$

German Standards (DIN 19 683, 1973) adapts Hallakorpi's formula to a peat soil with different layers with thickness T_1 , T_2 etc. and for a depth of drainage of 1.10 m . Subsidence in the uppermost layer with thickness T_1 is obtained from $S_1 = a\ (0.08T + 0.066)$ where S_1 is subsidence (m) in level 1. Subsidence in subsequent layers is obtained from $S_x = a \cdot 0.08\ T_x$, where S_x is subsidence (m) in level x with thickness T_x.
This formula assumes that watertable in the area to be drained is originally at the surface. When drainage depth is greater or less than 1.10 m, the corrected subsidence $S' = S \cdot (1.10 \pm b)/1.10$ metres where b = the depth of drainage below the surface.

Ostromecki (1956, cit Segeberg 1960) produced a formula of the form $S = A.\sqrt[3]{H \cdot t^2}$, where S = subsidence, m, H = original peat depth, m, t = final drain depth, m, and A is a coefficient based on peat density thus:

Dry bulk density (kg/m^3)	Condition	Coefficient A
56	floating	0.97
67	almost floating	0.69
79	loose	0.49
93	rather loose	0.35
109	rather dense	0.25
128	dense	0.18

Segeberg (1960) combined the formulae of Hallakorpi and Ostromecki to give a new formula $S = K \cdot t_n \cdot T^{0.707}$, where S = subsidence, m, t_n = final drain depth, m, T = original thickness of peat layer, m and K = coefficient based on volume of solids L_d according to $K = 0.05 + 1/L_d$. Values are as below:

Volume of solids, %	Condition	Coefficient K
less than 3	floating	0.43
3.0 - 4.9	loose	0.30
5.0 - 7.5	rather loose	0.22
7.6 - 12	rather dense	0.15
more than 12	dense	0.11

de Glopper (1972) recommends Segeberg's formula for prediction of subsidence in the peat layers above the watertable in acid peats of North-West Europe, i.e. peats which have a negligible rate of oxidation.

For subsidence in the soil layers below the watertable, Terzaghi & Peck (1956) provides the following formula: $dz/z = 1/c \cdot \ln (p_2/p_1)$, where dz = compaction (m), z = initial peat depth (m), p_1 = stress due to initial load (kp/m^2), p_2 = stress due to final load (kp/m^2) and c = coefficient of consolidation which for peat and gyttja soils has value 6 and for undrained clay soils, 9 (Axelsson, 1985). de Glopper (1972) describes the effective stress at any level as the difference between the saturated bulk density of all layers above that level and the porewater pressure. Since porewater pressure before and after drainage is 1000 kp/m^2 and 0 respectively, the increase in stress per metre lowering of the groundwater is 1000 kp/m^2.

Total subsidence according to de Glopper (1972) is the sum of shrinkage of the upper layers and compaction of the lower layers, assuming minimal oxidation.

Svadkovsky (1939) procuced a formula for subsidence prediction of form: $S = A x^3 - B x^2 + C x - D$, where S = subsidence, x = depth to watertable after drainage and A, B, C and D are constants based on peat type and consistency thus:

Group	Consistency	Low moor				High moor			
		A	B	C	D	A	B	C	D
1	loose	0.039	0.360	1.22	0.35	0.039	0.37	1.31	0.36
2	firm	0.015	0.167	0.70	0.27	0.015	0.19	0.82	0.25
3	medium	0.025	0.260	0.95	0.32	0.025	0.250	0.95	0.26

Svadkovsky's formula can only be applied to calculate subsidence in the first 10 years after initial drainage, during which time low moor peats of Group 1 will suffer 60% of their total subsidence, and those of Group 2 32% of their total subsidence (Svadkovsky, 1939/cit. Løddesøl, 1955).
Svadkovsky's formula is in general use in Norway for prediction of subsidence (Hovde, 1979). It has been found that, under Norwegian conditions, this formula gives a good approximation to subsidence even in periods longer than 10 years or after re-drainage.

Murashko (1969) takes distance from canal and thus drainage intensity into his calculations and provides formulae for predicting subsidence in the immediate vicinity of the drain and at a point midway between drains.
Subsidence at a point on the canal bank is predicted by integration of the basic relation $-dH/dt = A \cdot h \cdot H$, where dH/dt is the rate of subsidence with time, t in years, H = original peat depth, m, h = canal depth, m and A = constant of compression based on peat density. Integration of this gives

$S_n = A.H_o.\ (1 - \exp(-h \cdot (a + bt)))$, where S_n = subsidence in metres and a and b are coefficients of subsidence rate in the first and subsequent years after drainage respectively. For low moor in the Soviet Baltic region, a = 0.07 and b = 0.006.
Subsidence at a point midway between canals is obtained from

$$S_{n,x} = A.H_o\ (1 - \exp(-(h - Y)(a + bt)))\ \text{where}\ Y = (h - z - h_o)\frac{\ln(2(x-mh)/b)}{\ln(E-2mh)/b}$$

where other symbols are as above and z = depth to watertable midway between drains (m), h_o = depth of water in canal (m), E = distance between canals (m), b = drain diameter or canal width (m), x = distance of the point from the canal axis (m) and m = slope of trapezoidal canal side.
This formula is valid for calculation of subsidence of drainage within the life-time of the particular drainage technique, for open drains 5 - 10 years.

van der Molen (1975) cites work from the Netherlands adapting Terzaghi's formula either for uncompressed or precompressed peats. It is assumed that all naturally occurring peats have undergone compression at some stage in their formation due to dry spells, for example. The formula given by van der Molen for predicting subsidence in precompressed peats is

$$\frac{dz}{z} = \frac{A'}{A' + 0.62H + 38} \times \left[1 - \frac{H/A'}{0.0395 \cdot \ln(p_2) - 0.066} \right]$$

where z = original thickness of the peat (m), dz = compaction (m), A' = original moisture content of the peat (g/100g dry matter), H = organic content of the peat (g/100g dry matter), p_2 = stress due to final load (kg/m^2) and 0.62 and 0.0395 are empirical constants

This formula can be used to predict total subsidence in areas where oxidation of organic matter is not an important cause of subsidence.

Schothorst (1982) reports other formulae in use in the Netherlands. For shrinkage of peat layers above the watertable, the bulk density of peat before and after drainage can be compared thus:

$S_{sh} = d_2 \ (W_{h2} \ / \ W_{h1} - 1 \ )$ where d_2 is the actual thickness of the layer considered, W_{h1} = bulk density of organic matter below the maximum watertable depth and W_{h2} is the bulk density of organic matter above the watertable. Note that $W_h = W_s \cdot h$ where W_s = density of solids of total sample and h = weight percentage of organic matter, also that $W_s = W_h + W_m$, where W_m is bulk density of mineral elements. Total subsidence according to Schothorst (1982) is obtained by comparing bulk density of mineral elements before and after drainage with the relationship:

$S = d_2 \ (W_{m2} \ / \ W_{m1} - 1 \ )$ where W_{m2} and W_{m1} are the bulk densities of mineral elements above and below the watertable respectively. Subsidence due to oxidation of organic matter S_o is then derived, $S_o = S - S_{sh}$.

This approach is limited in that data for the peat after drainage are required so the formulae can only be used to predict subsidence where an area very similar to the area to be drained has already been drained and investigated.

Stephens and Stewart (1977) provide an equation for calculating subsidence due to oxidation of organic matter which is derived from the following:

$S_T = (a + bD) \ e^{K(T-T_0)}$, where S_T = biochemical subsidence rate at temperature T, D = depth to watertable, K = reaction rate constant, T_o = base soil temperature (5°C) and a and b are constants.

For a change in reaction rate with temperature Q such that reaction rate doubles with every 10°C rise in temperature ($Q_{10} = 2$) and for experimentally determined values of a and b, the equation simplifies to :

$$S_x = (-0.1035 + 0.0169\ D)\ 2^{0.1(T_x - 5)}$$

where S_x = subsidence due to oxidation of organic matter in lowmoor soils at location x, with mean annual temperature at the 10 cm level in the profile = T_x. D = depth to watertable. Biochemical activity is assumed to cease below 5°C.

Application of formulae to data from Bälinge Mossar

It was planned to use data from this investigation on Bälinge Mossar to check the accuracy and suitability of formulae under Swedish conditions. However, it must be remembered that the drainage of this area was not designed and carried out as part of a planned experiment. This present investigation is retrospective and during the 80 years since drainage was first carried out the area has been re-drained, the canals have been renovated a number of times and most fields in the area have been detail-drained by the owner/occupier. Most of the available formulae are designed to predict the amount of initial, rapid subsidence so that this can be allowed for in deciding depth of drainage.
An experiment to test the effectiveness of such formulae should record the properties of undrained peat, apply the formula, drain and wait for 5 - 10 years then compare actual subsidence with predicted. The observed subsidence in the Bälinge Mossar area as reported in Chapter 3 is a result of 80 years of main and detail drainage, cultivation and stump removal. All of these have contributed to shrinkage, compaction and oxidation and the overall effects are peat disappearance and loss of surface elevation.

In areas where sufficient data on peat properties before drainage are available, the formulae described in the early part of this chapter can be applied. Hallakorpi's formula can be applied using data form area A. We know that the original profile consisted of 1.3 - 1.4 m moss (Amblystegium) peat on 0.5 - 0.7 m forest peat on 0.2 - 0.4 m dy (Eriksson, 1912). From analyses of the undrained peat (see Chapter 3) these layers have the following properties:

Peat type	T_x (m)	Volume of solids (%)	Factor 'a'	Formula for layer
moss peat	1.35	11.7	1.375	$S_1 = 0.11T_1 + 0.10$
forest peat	0.60	12.8	1.000	$S_2 = 0.08T_2$
dy mud	0.30	5.7	2.000	$S_3 = 0.16T_3$

This gives the subsidence of the upper layers at a drainage depth of 1.1 m as $S = S_1 + S_2 + S_3$, S = <u>36</u> cm.

In 1984, the profile around this point consisted of 20 - 30 cm well-humified peat on 30 - 50 cm forest peat on 10 - 20 cm dy. This indicates a disappearance of peat from the upper layers and a compaction of the lower layers. There are, unfortunately, no data available to show the amount of subsidence of Bälinge peat in the first 10 years after initial drainage. Subsidence was on average 60 - 90 cm in the period 1908 - 1938 though at some points where peat was deep originally values as high as 120 cm occurred. Hallakorpi's formula is only designed to give a value by which drainage depth should be extended to allow for initial subsidence.

Segeberg's formula has a similar application. Calculation using data in the example above gave a subsidence value of <u>39</u> cm.

Terzaghi's formula gives a value for compaction of the lower layers by the increased load of the upper layers. Calculation according to this equation requires determination of the cumulative stress of successive layers on lower, compressible layers. A worked example for the profile in area A is given in the appendix. Compressible layers area assumed to be those above the 20 cm thick gravel layer in this case. Total compaction of the compressible layers is found to be <u>84</u> cm.

Total subsidence according to de Glopper is the sum of values obtained from Segeberg's and Terzaghi's formulae, in this case 39 + 84 = 123 cm. Actual subsidence in the area during a 30 year period after initial drainage was, as mentioned above, 60 - 90 cm.

Svadkovsky's formula is simpler to apply. Original peat in the Bälinge Mossar complex was medium firm and of lowmoor type (Tolf, 1897). Coefficients A, B, C and D thus have values of 0.025, 0.260, 0.95 and 0.32 respectively.and at a drainage depth of 1.1 m, the subsidence value obtained is <u>44</u> cm.

Subsidence near the drain is calculated according to Murashko's formula. For open drains, t = 10 years, depth of drainage = 1.1 m, initial peat thickness = 2.3 m and the coefficient A at a bulk density of 0.15 g/cm^3 and 80 % moisture content = 1.2 (from a nomogram given by Murashko, 1969), subsidence is 37 cm

Stephens and Stewart's equation predicts average annual rate of oxidation from measured average annual soil temperature (at 10 cm depth). No soil temperature data are available for the Bälinge area. Results are available from measurements on a clay soil at Ultuna. Considering the differences in temperature between a clay and a peat soil (Osvald, 1937), it was thought best not to use these local measurements. Temperature of a peat soil in Småland, southern Sweden, has been reported by Nyström (1936). Temperature at 10 cm depth was measured at 9 a.m. on a cultivated peat soil at Flahult research station and the annual average for 1929 was 4.7°C. The temperature in an average year is, according to Nyström, 0.6 - 0.8°C higher than this. Inserting a value of T_x = 5.4°C into the equation for a range of drainage depths, D, gives the following results:

D =	120 cm below the surface,	oxidation rate =	1.98 cm/year
D =	100 cm '' ''	, oxidation rate =	1.63 cm/year
D =	60 cm '' ''	, oxidation rate =	0.94 cm/year

The equation used above is not designed for periods of less than a year, so the results obtained for an average Swedish year when the temperature is less than 5°C for a considerable time may be inaccurate. For Swedish conditions, a model based on the summer half-year would be more suitable.

DISCUSSION

The formation of Bälinge Mossar as described in Chapter 1 is not only of historical interest but also of value for predictions of the future of the area. This is because it provides information on the original topography of the area and on the material which was deposited in the earlier stages of marsh formation. Thus we know that there were a series of bays or lakes in which deposition of material was greatest in the centre and tapered off towards the boundaries with rock outcrops. From Eriksson (1912) we know that gyttja deposition began and became thickest in the centre of the bays. Results from core sampling showed that peat is also thickest here. The significance of this in relation to the future cultivation of Bälinge Mossar will be discussed later in this section.

The amounts of subsidence which occurred in the Bälinge Mossar area (as reported in Chapter 2) show the disappearance of a cultivated peat soil with time. There is a lack of detailed information in that 20 - 30 years elapsed between measurements. The results provide an interesting case history of bog drainage and give an indication of what the final outcome of drainage and cultivation will be. Of especial relevance to the future is the rate of subsidence in the last 20 years, during which time no re-drainage of the main canals took place. Some of the observed subsidence may be due to compaction and stump removal and a greater part of it is probably due to oxidation of organic matter. The watertable in the areas investigated lay at 60 cm below the surface. At this watertable level, oxidation calculated by the Stephens & Stewart equation is 0.94 cm/year.
If peat disappearance continues at the same rate as in the period 1964 - 1984 then area A, where this rate was on average 1.8 cm/year and where an average depth of 60 cm peat remains, will no longer have any peat after about 30 years. The position will be somewhat similar in area C. In the part of area B where the profile is deepest, there is still 200 cm of peat and even at the highest subsidence rate recorded at this point (2.5 cm/year) there are still 80 years of cultivation life. At a short distance from this deep area, peat is already very shallow (20 - 40 cm) and subsidence rate at this point was on average 1.4 cm/year. This indicates a future of 14 - 28 years for the margins of area B.

The changes in physical properties of drained peat (Chapter 4) are a symptom of the compaction and oxidation which has occurred. Increase in dry bulk density and degree of humification as observed may lead to restriction of water movement in the peat, since hydraulic conductivity decreases with increasing peat density and humification (Baden & Eggelsmann, 1963; Boelter

1965). Furthermore drainable porosity, which indicates the maximum amount of water which can be removed by drainage, decreases with compaction and reduction of pore size and is low for decomposed peats (Sturges, 1968).

The aim of predicting subsidence by empirical formulae is to provide a measure of how deep drains must be installed to allow for subsidence. For example if predicted subsidence is 35 cm and desired drain depth is 1.1 m then the actual depth at which drains must be installed is 145 cm (Eggelsmann, 1975). Accuracy in this respect is very important in the installation of pipe drains.

Of the formulae described in Chapter 5, Svadkovsky's requires least preliminary data and is most easily applied. The formula was originally intended for prediction of subsidence in the first 10 years after initial drainage but as mentioned previously, Norwegian experience has shown that it can be applied to re-drainage or over a long period of time.

In practice, first-time drainage of natural peatlands for agriculture occurs rarely in Sweden nowadays. Most projects involve re-draining of a previously cultivated area. That considerable subsidence also occurs after re-drainage has been shown in this investigation. In area A, average subsidence in the period 1908 - 1938 was 44 % of the total subsidence which has taken place in the 76 years since first drainage. In the period 1938 - 1964 subsidence was 31 % of total and in the period 1964 - 1984 it was 25 % of total. Average values for area B in the same periods were 48, 27 and 25 % respectively and for area C, 46, 38 and 16 % respectively.

Subsidence after a future re-drainage would be expected to be at least equal to the rate exhibited in the last 20 years and is more likely to reach rates similar to those after the 1938 drainage.

Having accepted that peat disappearance is a process which will continue to a point where the soil can no longer be considered to be a peat soil, there are two important considerations:

a) rate of disappearance and ways to modify it

b) topography and soil type which will be exposed after peat disappearance.

The principle involved in conserving peat oxidation or wastage is simple and is based on a knowledge of the peat forming process. Peat is a deposit of plant remains which is built up under conditions unsuitable for micro-biological activity. Under normal (aerobic) conditions, organic matter falling on the soil is decomposed by the soil fauna at a rate correlated to temperature. In areas where peat formation occurs, conditions are anaerobic due to waterlogging in most cases. Peat formation often begins in basins or depressions which hold water. When peat is drained and aerated, the normal process of biodegradation begins and continues as long as conditions are favourable - that is when oxygen, organic matter and organisms are present and factors such as low temperature or pH do not inhibit microbial growth.

The only way in which to modify oxidation rate while maintaining an environment for crop growth is to control the watertable. A method used in Israel, where oxidation rates are very high, is to dam water outlets in the summer so that the watertable never falls below 60 cm (Avnimelech et al., 1978). This also controls vegetation growth in open canals during the summer (Pelkonen, 1980).

Another means of controlling oxidation rate is to restrict intensity of cultivation. Stenberg (1935) observed in experiments on a Swedish peat that subsidence rate was increased by ploughing, manuring, liming, harrowing, grazing and application of clay or sand mixes. This is due both to increased aeration and increased compaction.

Agerberg (1961) recorded subsidence rates on a Swedish peat under various crops in the period 1901 - 1960:

Crop	Subsidence		
	cm	cm/year	% of initial depth
Intensive cultivation incl. frequent potato crops	105	1.8	52
Grass for hay and silage	122	2.0	42
Permanent pasture	55	0.9	20
Forest	increase in peat depth of 3 mm/year		

The relationship between land use and cultivation pattern on Bälinge Mossar has already been described in Chapter 3. While care must be taken to avoid confusing the effects of cultivation intensity with those of other factors such as peat depth or drainage intensity, the following conclusions can be drawn:

Crop	Subsidence (cm/year) 1964 - 1984
5 years grass, 1 year fallow	1.9
Continuous cereal	2.1
Continuous grass ley, pasture	1.0
4-5 years grass ley, 1 year cereal	1.7

According to Hallgren & Berglund (1962) production of silage and hay, which reduces subsidence rate and thus eventually drainage costs, is profitable on a farm if:

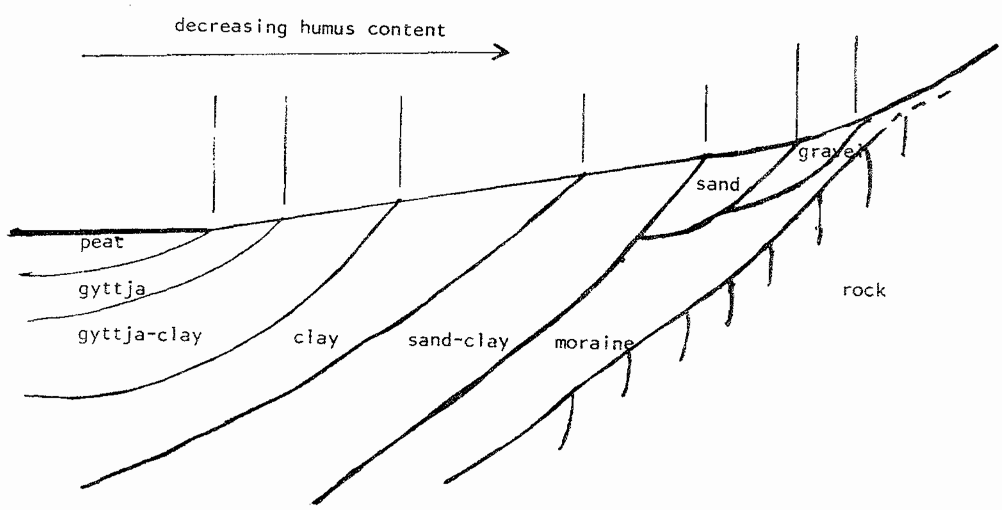
a) peat soil comprises only a part of the total farm area and hay or silage can be used in other farm enterprises,

b) low yields are obtained from cereals and other arable crops grown on the peat soil,

c) there is a high risk of flooding.

These authors consider that low intensity farming to conserve peat resources is economically justifiable if future profitability for farm produce is likely to exceed the present day returns. It is also noted that reduced rate of peat wastage delays the need for re-drainage and reduces investment cost to the farmer and to the government which supplies grant aid for drainage.

The diagram below shows the usual succession of soil types in central Sweden (After Magnusson et al., 1963)



Soil type can change within a short distance if the bedrock and moraine slope sharply. In fact, depth probing in areas A and B showed that at a distance of 20 m from a rock outcrop, the profile was more than 7 m deep. Probing also showed the layer under the peat to consist of gyttja, gyttja-clay, clay or a succession of sand and clay layers.

Determination of the cultivation potential of these lower layers is beyond the scope of this investigation, since it would require extensive probing and sampling of the entire moor complex and chemical analyses of the lower layers. In fact, if these layers are suitable for forest or crop production and can be satisfactorily drained, then using up the peat above through intensive can be financially worthwhile (Hallgren & Berglund, 1962).

The question of whether the exposed lower layers can be properly drained depends on the topography of the area. As mentioned, peat deposits are deepest in the centre of the former lakes. When most, or all, of the peat has disappeared, these areas lie lowest in elevation. Several sources (Valmari, 1977; Eggelsmann, 1978) recommend that in planning drainage of a peat area, the main outlet drains are sited to run through areas where peat is deepest. This has not been the case in Bälinge Mossar and when a stage is reached where a depression is formed, new outlet drains will be needed to connect these low-lying areas to the main canals. Furthermore, since the moor complex is surrounded by rock outcrops and mineral soils, the inevitable next stage in draining will be blasting through rock to achieve sufficient depth in the outlet canals and eventually installation of embankments and pumps.

So far as this investigation showed, there are a range of soil types which will gradually be exposed when peat wastage reaches its final stage. Berglund (1982) describes a range of cultivated peat profiles from Gotland, some of which have reached this final stage of peat disappearance. The following points can be noted: when gyttja and gyttja-clay soils are drained and exposed to air, a permanent system of cracks develops. If pH and sulphur content are not limiting for plant growth, these can be valuable agricultural soils although they are prone to dessication and resistant to re-wetting (Berglund, 1979).
When the lower layers consist of clay interspersed with sand layers which occur below plough depth, root development can be restricted by mechanical resistance of the coarse layer and by lack of water in dry periods.
Installations to control groundwater levels (pumps) could prevent dessication of peat and gyttja soils and the subsequent re-wetting resistance, as well as slowing rate of subsidence.

SUMMARY

This report begins with a description of the processes which led to the formation of the complex of peatlands known as Bälinge Mossar. The deposition of material at various stages in the marsh development is reflected in the present day profile's stratiagraphy.

Large scale drainage of the area, which consists of around 1800 ha, was begun in 1898, with a survey and investigation of the agricultural potential of the peat. Canal renovation was carried out periodically and a full re-drainage was carried out at the beginning of the 1940's.

The process of peat subsidence after drainage of this area can be followed in the period 1898 - 1984 by comparing maps from surveys in 1898, 1938, 1964 and 1984. Results from core sampling tests in 1898 and 1938 were compared with those from a new investigation in 1984.

These results show that subsidence in the area has been 1 - 3 cm/year in the 80 years since initial drainage. Actual amounts of subsidence which occurred varied between points as a result of factors such as intensity of drainage, intensity of cultivation and initial peat thickness. Subsidence was greatest in amount and annual rate where initial peat depth was greatest. At some points in the areas investigated, subsidence has been greater than 2 metres in the period 1900 - 1984 and this means that in some places, the present day peat thickness is around 20 cm and clay from the lower layers is being ploughed up.

Physical properties of drained peat were compared to properties of peat from an undrained section of moor. The latter samples were obtained at the edge of a domed Sphagnum mound near Åkerlänna. Results showed that dry bulk density and density of solids were increased and loss on ignition and porosity decreased by drainage. Data on the initial peat profile and properties of its layers were used in formulae for the prediction of subsidence, with the aim of comparing predicted and actual amounts. This case study was, however, not suited to such an exercise since most formulae are designed to predict subsidence in a relatively short period after initial drainage.

Since the process of surface subsidence and peat disappearance will continue until only a small amount of organic matter remains, the prospects for future drainage and agriculture in Bälinge Mossar are discussed. Important factors in the future cultivation potential of this area are its topography and the chemical and physical properties of material from the lower layers which will be exposed after peat wastage is complete.

SAMMANFATTNING

Mot bakgrund av Bälinge Mossars uppbyggnadshistoria behandlar föreliggande rapport detta myrområdes avvattning och den därpå följande nedsjunkningen av markytenivån. Bälinge Mossar är belägna cirka 20 km nordväst om Uppsala tätort. Den uppodlade delen av dem omfattar omkring 1800 ha.

Rapporten inleds med en beskrivning av det förlopp som ledde fram till myrområdets uppbyggnad. Genom studier av profiler från odikade delar av myrkomplexet kan man klarlägga de olika skedena i mossarnas utveckling, ända från tidig postglacial tid, då bildningsprocessen tog sin början med begynnande igenväxning av dåtida sjöar.

Efter några tidiga, föga framgångsrika försök att avvattna Bälinge Mossar, påbörjades 1898 en lagasyneförrättning och en undersökning av torvens odlingsvärde. Den första stora dikningen utfördes sedan 1904-1908 med efterföljande dikesrensningar då och då under tiden fram till år 1938. Till följd av försämrad torrläggning befanns det i slutet av 1930-talet nödvändigt med en fullständig omdikning av området.

Det är sedan länge känt att avvattning av en torvjord leder till sänkning av markytenivån. Sådana nivåförändringar förorsakas dels av krympning av och torvsvinn i lagren ovan grundvattenytan, dels av sammanpackning av lagren därunder.

Den markytesänkning som har skett på Bälinge Mossar p.g.a. deras avvattning har kunnat följas med hjälp av de kartor (skala 1:4000) över området, vilka ritades efter avvägningar 1898, 1938, 1964 och 1984. Resultaten av borrprovundersökningar 1898 och 1938 har jämförts med uppgifter inhämtade vid en ny sådan undersökning i november 1984.

Jämförelserna mellan resultaten från de olika avvägningarna visar att markytesänkningen inom området varit 1-3 cm i medeltal per år under de 80 år som förflutit sedan avvattningen i seklets början. De uppmätta värdenas storlek varierar inom de undersökta områdena alltefter skiftande ursprungligt torvdjup och skillnader i diknings- och odlingsintensitet. Markytesänkningens storlek och hastighet har varit störst där torvlagret från början var djupast.

Vid flera av provpunkterna har den sammanlagda markytesänkningen under perioden 1904-1984 uppgått till 2 meter. Sänkningen har varit så stor att torvdjupet nu på sina håll är mindre än 0,3 m och lera har i samband med plöjningar blandats in i torvskiktet.

De fysikaliska egenskaperna hos dränerad torv har jämförts med motsvarande egenskaper hos odränerad torv. Borrprov har tagits ut inom tre dikade områden (Norra myren, Södra myren vid Oxsätra och Södra myren vid Torvsätra) samt i den oavvattnade laggen till Römossen vid Åkeränna. Analyserna visar som väntat att såväl torra skrymdensiteten som kompaktdensiteten ökat och att glödningsförlusten liksom porositeten minskat efter dikning.

Uppgifter om den ursprungliga torvprofilen och om egenskaperna hos enskilda lager i denna har använts för beräkning av markytesänkning med hjälp av olika formler, hämtade från litteraturen. Avsikten har varit att jämföra de uppmätta värdena med beräknade värden i syfte att söka finna de formler som är bäst lämpade för svenska förhållanden.

Befintliga nivåuppgifter från Bälinge Mossar visar förändringen över så långa tidsavsnitt som 20-30 år. De snabba sänkningsförloppen som bör ha följt efter dikningen 1904-1908 och efter omdikningen i slutet av 1930-talet, kan tyvärr inte isoleras. Eftersom de flesta publicerade beräkningsformler är avsedda för skattning just av de relativt snabba sänkningarna de första åren efter en avvattning, så har beräkningsresultaten beklagligtvis inte kunnat nöjaktigt verifieras (eller falsifieras).

Bortodlingen och den därav föranledda markytesänkningen på torvjordarna i Bälingemosseområdet kommer att fortsätta till dess att nästan allt organiskt material har försvunnit. Det är därför viktigt att diskutera mossarnas framtida roll inom jordbruket.

Såvida jordmaterialet under torven är odlingsvärt och möjligt att avvattna, så kommer Bälinge Mossar att vara väl ägnade för jordbruk även i framtiden. I dessa avseenden föreligger emellertid ännu vissa oklarheter som det är viktigt att med det snaraste undanröja. Det vore t.ex. mycket värdefullt att veta vilka fysikaliska och kemiska egenskaper som materialet under torven har.

En annan faktor av stor vikt vid bedömning av myrområdets odlingsframtid är kännedomen om den underliggande fastmarkens topografi. För dikning av torvmarker är det en allmän rekommendation att från början lägga avloppsdikena där torvlagret är djupast, d.v.s. där ytsänkningen kan förväntas bli störst. Denna regel har inte följts på Bälinge Mossar, och detta kommer att skapa problem, bl.a. därför att svårdränerade svackor bildas ute på fälten. Den underliggande topografin har också betydelse för hur uttalade de avvattningsproblem kommer att bli som nästan alltid tillhör länge odlade myrområden, eftersom myrarna ju oftast har bildats i mer eller mindre utpräglade sänkor i fastmarksterrängen.

REFERENCES

Agerberg, L.S. 1961. Några studier av nivåförändringar på myrjord. Grundförbättring 14, 3: 141-176.

Andersson, G. 1909. The climate of Sweden in the Late-Quaternary period. Facts and theories. Sveriges Geol. Unders. Ser. C. No. 218.

Andersson, S. 1955. Markfysikaliska undersökningar i odlad jord. VIII. En experimentell metod. Grundförbättring 8, Specialnummer 2.

Avnimelech, Y., Dasberg, S., Harpaz, A. & Levin, I. 1978. Prevention of nitrate leakage from the Hula Basin, Israel: a case study in watershed management. Soil Sci. 125, 4: 233-238.

Axelson, U. 1985. Markytesänkning efter avvattning. Litteraturstudie samt egna undersökningar av ett område vid Emån. Sveriges Lantbruksuniversitet, Uppsala. Avd. för lantbrukets hydroteknik. Examensarbete.

Baden, W. & Eggelsmann, R. 1963. Wechselwirkung zwischen Oberflächen und Grundwasser im Moor. IAHS Publ. 63: 469-478.

Barrner, S. 1947. Bälinge mossars torrläggningsföretag, en beskrivning 1898 - 1947. Manuscript.

Berglund, G. 1979. Problemjordar. Statens lantbruksinformation Publ. 4/1979.

Berglund, K. 1982. Beskrivning av fem myrjordsprofiler från Gotland. Sveriges Lantbruksuniversitet, Uppsala. Avd. för lantbrukets hydroteknik. Rapport 125.

Boelter, D.H. 1965. Hydraulic conductivity of peats. Soil Sci. 100, 4: 227-231.

Bälinge mossars torrläggningsföretag 1898. 1938. Maps, drainage plans and minutes of meetings. Lantmäteriets arkiv, Uppsala.

Eggelsmann, R. 1975. Physical effects of drainage in peat soils and their forecasting. IAHS Publ. 105: 69-77.

Eggelsmann, R. 1978. Subsurface drainage instructions. ICID Bulletin 6.

Eriksson, J.V. 1912. Bälinge Mossars utvecklingshistoria och vegetation. Svensk Botanisk Tids. 6, 2: 105-188.

Fall, S. 1944. Bälinge mossars torrläggningsföretag. Lantbrukshögskolan, Uppsala. Inst. för agronomisk hydroteknik. Seminarieföredrag. Manuscript.

von Feilitzen, H. 1916. Mosskulturförenings sommarmöte i Uppsala: andra mötesdagen. Sv. Mosskulturfören. Tids. 13, 6: 479-481.

German Standards. 1973. Bestimmung der Moorsackung nach Entwässerung. DIN 19 683 Blatt 19, Berlin.

de Glopper, R.T. 1972. Subsidence. In: ILRI Fieldbook for Land and Water Experts. Provisional edition: 512-521.

Granlund, E. 1931. Kungshamnsmossens utvecklingshistoria jämte pollenanalytiska åldersbestämningar i Uppland. Sveriges Geol. Unders. Ser. C. Årsbok 25, 1: 22-51.

Granlund, E. 1932. De svenska högmossarnas geologi. A. Uppsalatrakten. Sveriges Geol. Unders. Ser. C. Årsbok 26, 1: 75-79.

Göransson, G & Hellsten, C. 1964. Angående den framtida markanvändningen inom Bälinge mossar. Lantbruksnämnden i Uppsala län, Uppsala. Manuscript.

Haglund, E. 1909. Om våra högmossars bildningssätt. Geol. Fören. Förhandl. 31, 5: 376-397.

Hallakorpi, I.A. 1938. Några iakttagelser rörande myrars och myrdräners sättning i Finland. Lantbruksveckan Handl. 27: 46-59.

Hallgren, G & Berglund, G. 1962. De odlade myrjordarnas omfattning och användning. Inst. för agronomisk hydroteknik, Lantbrukshögskolan, Uppsala.

Hartmark, H. 1958. Setninger av myr som følge av grunnvannssenkning. Medd. fra Det norske myrselskap 56, 4: 105-114.

Hovde, O. 1979. Myrsynking. Jord og Myr 3, 1: 72-81.

Ilnicki, P. & Burghardt, W. 1981. Sackung in wiederholt entwässerten Hochmooren des nordwestdeutschen Flachlandes. 6. Bericht. Z.f. Kulturtechnik und Flurbereinigung 22, 2: 112-121.

Kaitera, P. 1954. Om uppskattning av markytans sättning vid torrläggningsarbetena. Nord. Jordbrugsforsk. 36: 532-537.

Lie, O. 1981. Vurdering av myr til dyrking. Jord og Myr 5, 1: 1-13.

Løddesøl, A. 1955. Orientering om synkningsproblemet på myr. Medd. fra Det norske myrselskap 53, 1: 7-36.

Magnusson, N.H. & Granlund, E. 1936. Sveriges Geologi. Norstedt & Söner, Stockholm.

Magnusson, N.H., Lundqvist, G. & Regnéll, G. 1963. Sveriges Geologi. 4:e uppl. Svenska Bokförlaget, Stockholm.

Malm, E.A. 1933. Sättningen av Leteensuo torvmarks yta under åren 1903 - 1933. Fin. Mosskulturfören. Årsbok 37, 2: 135-140.

van der Molen, W.H. 1975. Subsidence of peat soils after drainage. IAHS Publ. 105: 183-186.

Moore, P.D. & Bellamy, D.J. 1974. Peatlands. Elek Science, London.

Murashko, A.I. 1969. Compression of the peat-bogs after draining. IAHS Publ. 89, Vol. II. Colleque de Tokyo: 535-546.

Nyström, E. 1936. Sammandrag av de meteorologiska observationerna vid försöksgårdarna Flahult och Gisselås under år 1929. Sv. Mosskulturfören. Tids. 15, 2: 177-200.

Ostromecki, J. 1956. Designing the longitudinal profile of ditches and drainage for peat lands, with consideration given to subsidence (English summary). Roczniki Nauk Rolniczych Seria F 71, 3: 739-778.

Osvald, H. 1937. Myrar och myrodling. Kooperativa Förbundets Bokförlag, Stockholm.

Pelkonen, E. 1980. Effect of damming on watertable depth and ditch condition (English summary). Suo 31, 2-3: 33-39.

Prytz, K. 1943. Tørvemassens sammensynkning i Store Vildmose. Maaleresultater 1923 - 1941. Nord. Jordbrugsforsk. 25: 371-388.

Sahlin, B. 1916. Bälinge mossars uppodling och nuvarande kulturtillstånd. Sv. Mosskulturfören. Tids. 13, 5: 377-382.

Schothorst, C.J. 1977. Subsidence of low moor peat soils in the western Netherlands. Geoderma 17, 4: 265-291.

Schothorst, C.J. 1982. Drainage and behaviour of peat soils. ILRI Publ. 30: 153-163.

Segeberg, H. 1960. Moorsackungen durch Grundwasserabsenkung und deren Vorausberechnung mit Hilfe empirischer Formeln. Z.f. Kulturtechnik und Flurbereinigung 1: 144-161.

Sernander, R. 1909. Hornborgasjöns nivåförändringar och våra högmossars bildningssätt. Geol. Fören. Förhandl. 31, 4: 225-263.

Sorteberg, A. 1973. Synkingsproblemer på dyrket myrjord. Medd. fra Det norske myrselskap 71, 5: 180-184.

Stenberg, M. 1935. Gisselåsmyrens sättning under tioårsperioden 1922 - 1932. Lantbrukveckan Handl. 24: 172-191.

Stephens, J.C. & Speir, W.A. 1969. Subsidence of organic soils in the USA. IAHS Publ. 89, Vol. II. Colleque de Tokyo: 523-534.

Stephens, J.C. & Stewart, E.H. 1977. Effect of climate on organic soil subsidence. IAHS Publ. 121: 647-655.

Sturges, D.L. 1968. Hydrological properties of peat from a Wyoming mountain bog. Soil Sci. 106, 4: 262-264.

Svadkovsky, E.G. 1939. Deposition of peat and diminution of the depth of draining canals in marshlands. Vsesoujuznaja ordena Lenina akademija sel'skochozjajstvennych nauk imeni V.I. Lenina. Doklady 1939, 23/24: 56-59.

Terzaghi, K & Peck, R. 1956. Soil Mechanics in Engineering Practice.

Tolf, R. 1897. Torfmossundersökningar inom Bälinge härad i Uppsala län. Sv. Mosskulturfören. Tids. 14, 1: 25-31.

Valmari, A. 1977. Torrläggningsfrågor på myrjordar. Nord. Jordbrugsforsk. 59, 4: 640-643.

Wellenius, J.C. 1916a. Bälinge mossar. A. Mossmarkernas torrläggning. Sv. Mosskulturfören. Tids. 13, 5: 374-376.

Wellenius, J.C. 1916b. Föredrag om Bälinge mossar. Sv. Mosskulturfören. Tids. 13, 6: 468-476.

Öhman, J.O. 1966. Företagsekonomisk analys av jordbrukets förutsättningar i Bälingemosseområdet. Lantbrukshögskolan, Uppsala. Inst. för ekonomi och statistik. Examensarbete i driftsekonomi.

APPENDIX

Physical properties of undrained peat, Römossen.

Level (cm)	Peat type	Dry Bulk density (g/cm3)	Saturated Bulk density (g/cm3)	Loss on ignition (%)	Density of solids (g/cm^3)	Porosity (vol.%)
0 - 10	Sphagnum	0.18	1.04	93	1.44	87.5
10 - 20	''	0,17	1.07	93	1.45	88.3
20 - 30	''	0.18	1.11	92	1.56	88.5
30 - 40	''	0.17	1.15	89	1.43	88.2
40-- 50	Forest	0.19	1.05	90	1.41	86.5
50 - 60	''	0.19	1.15	87	1.50	87.4
60 - 70	''	0.19	1.24	88	1.43	86.7
70 - 80	''	0.19	1.26	89	1.48	87.2
80 - 90	''	0.19	1.17	89	1.46	87.0
90 -100	Fen	0.18	1.04	89	1.45	91.2
100 -110	''	0.14	1.14	89	1.39	89.9
110 -120	''	0.15	1.24	89	1.57	90.4
120 -130	''	0.17	1.13	91	1.42	88.0
130 -140	Leafy	0.17	1.22	91	1.53	88.9
140 -150	Carex	0.14	1.01	90	1.45	93.1
150 -160	''	0.14	1.16	90	1.44	90.3
160 -170	''	0.14	1.26	92	1.41	90.1
170 -180	Equisetum	0.17	1.23	93	1.55	89.0
180 -190	''	0.17	1.18	93	1.46	88.3
190 -200	Phragmites	0.12	1.00	88	2.10	94.4
200 -210	''	0.12	1.19	89	2.10	94.3
210 -220	Phrag./gyttja	0.15	1.27	90	2.10	92.8
200 -230	''	0.16	1.29	69	2.10	92.4
230 -240	Gyttja	0.26	1.27	28	2.00	87.0
240 -250	''	0.27	1.16	20	2.00	87.0
600 -610	Shell gyttja	0.47		10	2.6	56
610 -620	Gyttja clay	0.54		10	2.6	59
620 -630	Sand/clay	1.12		15	2,6	34
630 -640	Clay	1.42		11	2.6	38
64o -650	Sand/clay	1.09		14	2.6	38

Physical properties of peats in area A, Södra Myren: 0 - 50 cm layer.

Point	Dry bulk density (g/cm^3)	Density of solids (g/cm^3)	Loss on ignition (%)	pH	Porosity (vol.%)
273	0.23	1.62	85	5.8	85.8
279	0.22	1.60	87	5.7	86.2
280	0.20	1.60	88	5.7	87.5
281	0.23	1.63	85	5.6	85.9
282	0.23	1.62	84	5.6	85.8
283	0.23	1.75	79	5.7	86.8
284	0.23	1.72	87	5.4	86.6
293	0.26	1.65	83	5.5	84.2
294	0.27	1.80	64	5.7	85.0
295	0.25	1.74	77	5.6	85.6
296	0.27	1.67	76	5.6	83.8
297	0.38	1.76	62	5.7	78.4
298	0.26	1.67	82	5.6	84.4
299	0.22	1.57	82	5.6	86.0
300	0.27	1.67	76	6.1	83.8
50 - 100 cm layer					
284	0.21	1.58	87	5.4	86.7
Means for 0 - 50 cm layer					
	0.24	1.66	80	5.7	85.5

Physical properties of peat in area B, Norra Myren: 0 - 50 cm layer

Point	Dry bulk density (g/cm^3)	Density of solids (g/cm^3)	Loss on ignition (%)	pH	Porosity (vol.%)
35	0.24	1.6	86	5.2	85.0
36	0.24	1.6	86	5.4	85.0
39	0.33	1.7	73	6.0	80.6
50	0.29	1.6	83	5.7	81.8
54	0.27	1.7	85	5.6	84.1
55	0.25	1.5	85	5.7	85.3
56	0.28	1.5	85	5.4	81.3
57	0.22	1.5	86	5.4	85.3
58	0.24	1.5	86	5.6	84.0
95	0.33	1.6	75	5.7	78.0
96	0.27	1.5	86	5.5	83.1
97	0.25	1.6	86	5.3	84.3
98	0.25	1.5	87	5.2	83.3
99	0.21	1.5	87	5.3	86.0
99a	0.23	1.5	80	5.3	84.7
99b	0.27	1.5	75	5.5	82.0
99c	0.26	1.5	86	5.5	82.7
100	0.25	1.5	87	5.4	85.3
101	0.27	1.6	86	5.4	83.1
102	0.27	1.7	83	5.3	84.1

Means for 0 - 50 cm layer

	0.24	1.56	83.6	5.5	83.3

Physical properties of peat from area B, Norra Myren: 50 - 100 cm layer

Point	Porosity (vol.%)	Dry bulk density (g/cm^3)	Density of solids (g/cm^3)	Loss on ignition (%)	pH	Saturated bulk density (g/cm^3)
35	86.0	0.21	1.5	87	5.1	1.27
36	90.0	0.15	1.5	90	5.3	1.18
56	86.8	0.21	1.6	83	5.1	1.23
57	88.8	0.19	1.7	84	5.5	1.14
58	87.3	0.19	1.5	84	5.7	1.14
95	85.3	0.22	1.5	89	5.5	1.17
96	88.0	0.18	1.5	87	5.3	1.13
97	86.7	0.20	1.5	88	5.3	1.12
98	88.0	0.18	1.5	91	5.2	1.16
99	86.4	0.19	1.4	89	5.6	1.17
99a	90.0	0.14	1.4	91	5.3	1.10
99b	88.6	0.16	1.4	92	5.3	1.15
99c	88.7	0.17	1.5	92	5.3	1.14
100	87.3	0.19	1.5	90	5.4	1.17
101	90.0	0.14	1.4	91	5.5	1.11
102	87.5	0.20	1.6	86	5.5	1.14

Means for 50 - 100 cm layer

	87.8	0.18	1.50	88.4	5.4	1.16

Physical properties of peat from area B, Norra Myren: 100 - 150 cm layer

Point	Porosity (vol.%)	Dry bulk density (g/cm^3)	Density of solids (g/cm^3)	Loss on ignition (%)	pH	Saturated bulk density (g/cm^3)
35	90.6	0.15	1.6	75	5.5	1,16
36	90.7	0.13	1.4	86	5.4	1,12
58	89.3	0.15	1.4	84	5.4	1.12
95	90.0	0.15	1.5	87	5.4	1.19
96	90.7	0.14	1.5	89	5.3	1.10
97	91.9	0.13	1.6	86	5.3	1.00
98	91.3	0.13	1.5	91	5.5	1.13
99	90.6	0.15	1.6	88	5.3	1.12
99a	91.4	0.12	1.4	90	5.6	1.10
99b	91.4	0.12	1.4	89	5.7	1.10
99c	91.3	0.13	1.5	89	5.5	1.12
100	90.0	0.15	1.5	91	5.4	1.15
101	90.0	0.15	1.5	86	5.2	1.14
Means for 100 - 150 cm layer						
	90.7	0.138	1.49	86.3	5.4	1.12
150 - 200 cm layer:						
96	91.3	0.13	1.5	78	5.7	1.10
98	92.0	0.12	1.5	81	6.0	1.11
99	90.0	0,16	1.6	79	5.7	1.14
99a	92.2	0.10	1.4	81	5.7	1.08
99c	91.4	0.12	1.4	84	5.8	1.10
100	89.3	0.16	1.4	78	5.7	1.14
Means for 150 - 200 cm level						
	91.0	0.132	1.48	79.8	5.8	1.09

Physical properties of peat from area C, Torvsätra: 0 - 50 cm layer

Point	Dry bulk density (g/cm3)	Density of solids (g/cm3)	Loss on ignition (%)	pH	Porosity (vol.%)
389	0.23	1.6	86	5.7	86.3
392	0.23	1.5	88	5.6	85.3
400	0,24	1.6	82	5.5	85.2
401	0.23	1.6	88	5.5	86.0
402	0.23	1.6	85	5.5	86.0
407	0.23	1.6	86	5.6	86.4
408	0.25	1.6	85	5.6	84.3
409	0.29	1.7	75	5.6	83.2
427	0,25	1.7	75	6.1	85.2
436	0.29	1.7	74	6.1	83.2
437	0.28	1.7	74	6.0	84.0
438	0.26	1.6	82	6.0	84.4
Means for 0 - 50 cm layer					
	0,25	1.62	81.7	5.7	84.8

Worked example of Terzaghi's formula

Application of Terzaghi's formula, $dz/z = 1/c \cdot \ln(p2/p1)$, to the Södra Myren profile, 1.35 m moss peat on 0.65 m forest peat on 0.30 m dy on 0.2 m gyttja on clay.

The coefficient c has value 6 for peat and gyttja, 9 for clay.
Depth of drainage is set at 1.1 m and depth to the incompressible layer (gravel) is 3.2 m. The 1.1 thick layer of moss peat above the watertable thus exerts a compacting force on a 2.1 m thick compressible layer. The calculation is as follows, where h = layer thickness, $\rho_{sat.}$ = saturated bulk density of the layer, ρ_{H2O} = density of water and p = stress = $(\rho_{sat} - \rho_{H2O})(h)$. Note that the difference in stress due to drainage is caused by the removal of water from the upper layer and that ρ_{H2O} = 1000 before and 0 after drainage.

Level (m)	Peat type	Layer depth, m	ρ_{sat}, kg/m^3	$(\rho_{sat}-\rho_{H2O})(h)$	p_1, kp/m^2	p2, kp/m^2
0 -1.10	moss	1.10	1100	-	110	1210
watertable						
1.10-1.35	moss	0.25	1100	25	135	1235
1.35-2.00	forest	0.65	1150	90	225	1325
2.00-2.30	dy	0.30	1100	30	255	1625
2.30-2.50	gyttja	0.20	1270	54	309	1679
2.50-3.20	clay	0.70	1460	322	631	2001

Note that p_1 and p_2 differ only in the drained layer but that this affects the cumulative p_2 figure in each successive layer. Applying Terzaghi's formula to the overall profile gives:

$$dz = \frac{2.1}{6} \times \ln\left(\frac{1210}{110}\right) = 84 \text{ cm}$$

The amount by which individual layers below the watertable are compacted is calculated by applying Terzaghi's formula to successive layers:

Layer	Compaction exerted by layers above this level
1.35 - 3.20	$dz = 1.85/6 \cdot \ln(1235/135) = 68$ cm
2.00 - 3.20	$dz = 1.20/6 \cdot \ln(1325/225) = 35$ cm
2.30 - 3.20	$dz = 0.90/6 \cdot \ln(1625/255) = 27$ cm
2.50 - 3.20	$dz = 0.70/9 \cdot \ln(1679/309) = 13$ cm

Compaction of individual layers is obtained by subtraction, e.g. of the 25 cm moss peat under the watertable = 84 - 68, 16cm.
Similarly the 65 cm thick forest peat layer subsided by 68 - 35, 33 cm, the 30 cm dy layer by 35 - 27, 8 cm and the 20 cm gyttja layer by 27 - 13, 14 cm. The clay layer between 2.5 and 3.2 m depth compacted by 13 cm (see table above)

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