Acta Palaeobot. 41(1): 43–67, 2001

Development of bogs in a coast-inland transect in northern Norway

KARL-DAG VORREN

Department of Biology University of Tromsø, N-9037 Tromsø, Norway, e-mail: karldag@ibg.uit.no

Received 19 March 2001; accepted for publication 9 July 2001

ABSTRACT. Bio- and litho-stratigraphy of eight ombrotrophic bogs and one fen in a 76 km long transect from coast to the interior of the district of Troms were studied. The general mode of development of a bog was from an initial carr or swamp forest via a more or less open Cyperaceae-Amblystegiaceae fen to an open Ericaceae-*Sphagnum* bog with hummocks and hollows. The most marked litho- and biostratigraphical changes concentrated about 2750 ^{14}C-years BP (2855 cal. years BP). Transition to ombrotrophic environments normally occurred with some time lag after a climatically induced lithostratigraphical change. This lithostratigraphical transition most frequently occurred during the time interval 3355–2760 BP. The oldest date of the transition was 4465 BP and the youngest (interpolated) date 2400 BP.

KEY WORDS: ombrotrophic mires, palaeoclimate, litho- and bio- stratigraphy, northern Norway

INTRODUCTION

The Målselv river catchment area, and the Malangen fjord dominate the area of central Troms (Fig. 1). Mountains, the crests of which reach 1200–1700 m a.s.l., distinguish the areas between the river valleys.

Woodlands and forest stands dominated by birch (*Betula pubescens* Ehrh.), grey alder (*Alnus incana* (L.) Moench.) and pine (*Pinus sylvestris* L.) characterize the morainic, glaciofluvial and marine deposits of the valleys. In

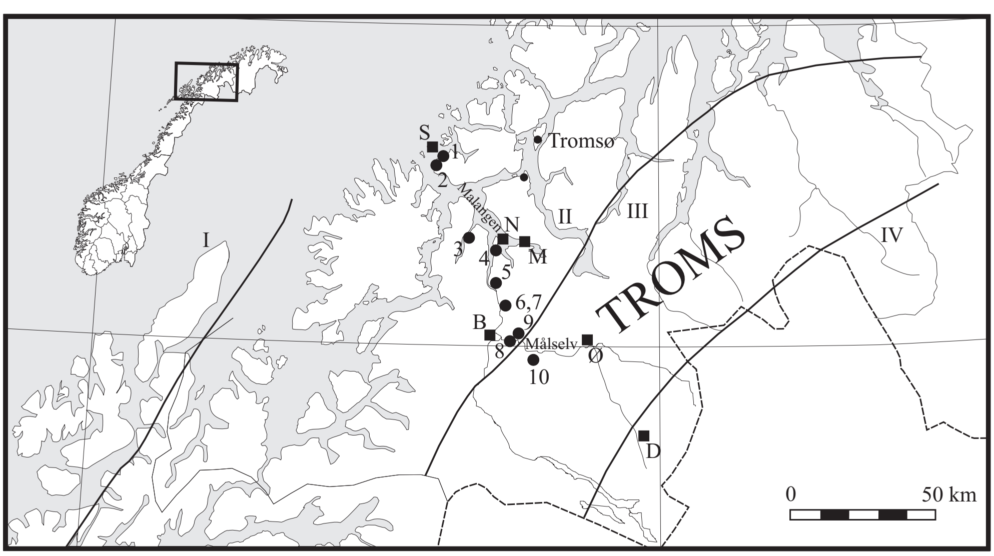

Fig. 1. Position of mire sites 1–10 and meteorological stations (S, M, B, Ø and D). I-IV represents four mire-complex sections along the oceanic-continental gradient

addition, different *Salix* species and aspen (*Populus tremula* L.) may play important roles in some of the forest types.

On these Quaternary deposits the humid climate of the region induces extensive mire and bog formation, even in areas with an annual precipitation of about 500 mm and less.

The climatically balanced climax stage of the lowland mires west of the section boundary II/III (Fig. 1) is an ombrotrophic bog (cf. Eurola & Vorren 1980). East of this line there is a transitional section (III) with both ombrotrophic and minerotrophic mire complexes. There is also an altitudinal trend from the lowland bog complexes to mire complexes characterized by sloping fens in the subalpine birch region.

The present investigation concerns development of mires and bogs in section II and III along a northwest-southeast transect (Fig. 1). The transect covers the coast at the mouth of the Malangen fjord (sites 1 and 2, Table 1), via the fjord head of Malangen (sites 3 and 4), and the lower part of the valley of Målselvdalen (sites 5–7), to the middle part of Målselvdalen (sites 8–10). Sites 1–9 occur within the mire section II (the sub-maritime *Racomitrium-Calluna* bog section), whereas site 10 belongs to section III. Site 10 is also the only one representing the sub-alpine birch region. The other sites are situated in the "pre-alpine" vegetation belt (cf. Elven & Vorren 1980). The transect is limited by the latitudes 68°50' to 69°35' N. Lat. and 18°05' to 18°50' E. Long., and constitutes a ca. 76 × 16 km large rectangle.

The purpose of this investigation is to highlight regional climatic signals in bio- and lithostratigraphy, and to study the succession/development towards ombrogenic environments.

THE INVESTIGATION AREA

CLIMATE

The maritime-continental climate gradient from northwest to southeast is summarized in Table 2 (extracted from Aune 1993, Førland 1993, and Bruun 1967). Typical features are: 1) Decrease in annual precipitation 940–659 mm to 282 mm in Dividalen. 2) Decrease in annual mean temperature (3.9°–0.9°C). 3) Increasing, or as an "arcuate" form, mean June-August (summer) temperatures from coast to inland (10.7°C in the coastal region, 11.9°C in the fjord region, to 11.8°C in the middle valley region to 11.3°C in Dividalen). 3) The annual mean amplitude between the warmest and the coldest month increases, or exhibits an "arcuate" form from coast to inland (13.8°C at the coast, 19.1°C in the fjord region to 24.7°C in the middle part of the valley to 23.4°C in Dividalen). 4) Increasing amount of summer precipitation as related to the annual precipita-

Table 1. The investigated mire sites. All sites are positioned within the UTM grid 34W. Cores from all sites have been pollen-analyzed. For a limited number of sites some chemo-stratigraphical parameters, colorimetric humification and concentration/influx of pollen and spores have been analyzed

Site No.	Site name	Mire area (da)	Core length, compressed (cm)	UTM position of coring site	Altitude, m a.s.l.	Concentration/ influx data	Humification, colorimetric	Mg, Ca
1	Austeinmyra	10	168	CC847247	25	+		
2	Brensholmyra 1	910	178	CC851229	11	+		
3	Straumen	30	156	CB952979	12			
4	Målsnes	5	285	DB036924	45	+		
5	Aspmo	60	243	DB033774	25	+		
6	Olsborg hummock	240	55	DB050739	33	+	+	+
7	Olsborgmyra 2	240	123	DB050739	33	+	+	+
8	Smedrud (Bjørndalsmyra)	250	151	DB067611	75		+	
9	Fossli	15	180	DB073617	100			
10	Vardfjellmyra	10	225	DB115549	365	+	+	

Table 2. Some climate parameters from the meteorological stations Sommarøy (S), Meistervik (M), Bardufoss (B), Øverbygd (Ø), Dividalen (D) (the 1961–90 normal). Positions in Fig. 1

Site	Mean temperature °C													Vegetation period days t≥6°C*	Precipitation mm	
	J	F	M	A	M	J	J	A	S	O	N	D	Yr	Days	Jun-S	Yr
S	-1.9	-1.9	-1.0	1.7	5.5	8.9	11.9	11.4	8.1	4.5	1.0	-1.1	3..9	136	290	940
M	-6.0	-5.5	-3.0	0.9	5.8	10.5	13.1	12.0	7.2	2.7	-2.0	-4.7	2.6	130**	284	860
B	-10.4	-8.9	-5.4	-0.2	5.6	10.5	13.0	11.5	6.3	0.9	-5.5	-8.9	0.7	125	222	652
Ø	-10.2	-8.7	-5.2	-0.2	5.5	10.7	13.2	11.5	6.4	1.4	-4.9	-8.7	0.9	125	241	659
D	-9.4	-8.2	-5.5	-0.8	5.0	10.3	12.8	10.9	6.3	1.0	-4.8	-8.0	0.8	122	164	282

* period 1931–60 ** Data from a neighbouring station: Navaren (N)

tion, along the coast-inland transect (30.8%, 34.0%, 36.6% up to 58.0% in Dividalen).

The oceanity of the climate is probably best differentiated by means of the oceanity-continentality index of Kotilainen (1933). This index includes the mean temperature of the warmest and the coldest month, the length of spring, summer and autumn as well as the annual precipitation. The maritime coast (Sommarøy) has an index value of ca. 117, the sub-maritime fjord head (Meistervik/Navaren) ca. 50, the sub-maritime to sub-continental main valley (Bardufoss and Øverbygd) ca. 30, and the sub-continental lateral valley (Dividalen) ca. 13.

The only station with a clearly sub-continental climate, Dividalen, is situated outside the present transect. The precipitation pattern, with high autumn and winter precipitation, characterizes the investigation area as having a maritime or oceanic precipitation regime, whereas the mean annual temperature amplitude points to a strong thermal gradient towards a sub-continental temperature climate regime.

GEOLOGY

The geology of the area is characterized by the North-Norwegian Cambro-Silurian mica schist formation (Sigmond et al. 1984) on the mainland (valley and fjord district) and acid gneiss on the coastal part of the islands. Most of the bogs in the valley and fjord region lie on Quaternary leached deposits of mainly sand and gravel. Below the sites on the island, the mineral substrates are mainly marine deposits, frequently coarse shell sand and gravel. In the island district, the marine limit was formed about 10 500 BP (as the Main Line), and during the period 10 000 – 9500 BP in the fjord and valley district (G. Corner, T. Vorren, pers. comm; Sollid & Torp 1984). The marine limit reaches an altitude of about 27 m a.s.l. in the northwest and (theoretically because of blocking inland ice) 90 m a.s.l. in the southeastern part of the investigation area.

FLORA AND VEGETATION

The flora atlases of Benum (1958) and Engelskjøn and Skifte (1995) of the county of Troms give detailed information of the distribution of vascular plants in the study area. Fremstad and Øvstedal (1978) and Spjelkavik (1986) have described the forest vegetation in the southern part of the district (the valley and inner fjord region). Vorren and Johansen (1990) have investigated the mire vegetation in different altitudes of an area in the south, and Vorren et al. (1999) have described the regional lowland mire vegetation of Troms and the adjacent part of Nordland county.

VEGETATION HISTORY

From the southern part of the study area some simplified pollen diagrams from both lakes and bogs have been published, mainly from higher altitudes (Alm et al. 1996, Vorren et al. 1996, Vorren & Stavseth 1996), with the purpose of reconstructing Holocene forest-line displacements. The main features are:

Ca. 9500–9000 BP: Deglaciation and succession of snowbed and heath vegetation, which by 9200 BP was replaced by a *Hippophaë – Betula pubescens* vegetation and later by a *Juniperus – Betula pubescens* vegetation. The *Betula pubescens* altitudinal limit about 8600 BP was about 850 m a.s.l. (the contemporary theoretical sea level isobases at the southern end of the present transect were situated at 80 m a.s.l.).

Ca. 7500–7000 BP: Establishment of pine and alder forests up to 600–700 m a.s.l.

Ca. 5000 BP: Marked depression of the forest-lines.

Ca. 4000–3700 BP: Final depression of the forest lines down to approximately their present situation.

Ca. 2500 BP: Transition to a more cool-humid climate with further reduction of the pine and alder forests, and replacement of this comparatively thermophilous vegetation by sub-arctic birch forest communities.

Vorren and Vorren (1976) studied a palsa bog in southeastern Troms. The palsa formation probably took place there during the "Little Ice Age", although the mire formation started as early as about 8600 BP according to an unpublished radiocarbon date (Rággastatjćggi 215–220 cm: 8655 ±220, GX-6078).

Bogs in southwestern Troms (Vorren & Alm 1985) show marked changes in the bio- stratigraphy about 5300–5000 BP. The ombrotrophic *Calluna-Rubus chamaemorus-Sphagnum* peat formation in the coastal bogs started at 5300 BP in the most oceanic position (Elgsnes) and at 4000 BP in a more eastern position (Vinja).

PRIMARY STUDY OBJECTS: THE *CALLUNA-RACOMITRIUM* BOGS

The bogs are termed sub-oceanic ombrogenic by Vorren et al. (1999). The gross form is eccentric. In special cases such as Olsborgmyra, (Nos 6–7, Fig. 1), comparatively steep marginal slopes may occur. Former erosion of the bog expanse is often evident (subsidence of the bog plane, and large pools with irregular outlines replacing the regular string hummock/hollow pattern, which is arranged perpendicularly to the direction of drainage). The marginal slope, which may be 20–50 m broad, is characterized by homogeneous dwarf-shrub vegetation, with *Empetrum nigrum* ssp. *hermaphroditum*, *Vaccinium uliginosum*, *Sphagnum fuscum*, *Pleurozium schreberi* and *Cladonia rangiferina* as dominating components (cf. Vorren 1993). The bog expanse is characterized by hollows normally dominated either by *Trichophorum cespitosum* and *Sphagnum tenellum*, or by liverworts and lichens, or naked peat mud and algae such as *Zygogonium ericetorum*. In contrast to more continental bogs (cf. Ruuhijärvi 1963), carpet vegetation (cf. Sjörs 1950) is rare in the regional mire section II. However, in section III at the valley floor, such features exist in eccentric bog elements occurring at the margins of the intermediary "oxbow mires" (i.e. in-filled former river meanders). *Calluna-Racomitrium* vegetation and *Vaccinium microcarpum-Sphagnum fuscum* vegetation characterize the higher and lower string hummocks. A formal phyto-sociological nomenclature of these vegetation units is suggested by Vorren et al. (1999).

MATERIAL AND METHOD

FIELD WORK

Eight bogs and one meso-eutrophic fen have been cored. The latter (Fossli, no. 9, Table 1) should be considered a marginal sloping fen. It is evidently eroded in the upper peat layers. The cores were generally sampled from the proximal parts of the eccentric bogs where erosion is not so frequent. However, the Olsborg 2 (hollow) sequence proved to be eroded in the upper part, as peat representing the last about 1500 years appeared to be removed. At the Olsborg bog (sites 6 and 7, Table 3) transects were cored and levelled to assess the gross morphology and stratigraphy (Vorren 1993).

The cores were sampled in sharp-edged plastic tubes by pounding on a specially adapted metal lid placed on the top of the tube, and dug out by means of a cross-spade. Continuous cores of 2.5 m are possible to retrieve with this method. Additional, deeper sediments were sampled by means of a Hiller corer in two cases: the Målsnes and Aspmo bogs. The beating-down of tubes inevitably causes a compression of peat. For a 2 m long core a compression of 10–30 cm may occur. It seems that compression mainly affects the low-humified peat layers, especially low-humified *Sphagnum lindbergii* peat. When sedimentation rates were calculated, they were calculated on the basis of the length of the compressed cores.

In the laboratory the tubes were sawn longitudinally in two halves. The cores were cleaned, the peat types classified, and the humification determined according to the von Post's scale (Post von & Granlund 1926). In a few cases (Austeinmyra, Olsborgmyra and Vardfjellmyra) the cores were sliced continuously in 1 cm thick slices and stored in airtight plastic bags. After pollen analysis, samples for radiocarbon dating were removed from the cores, which were then stored in plastic tubes, or, when sliced, in plastic boxes.

POLLEN AND SPORES

The pollen samples were 1 cm^3, measured with disposable syringes. The preparation was carried out in accordance with the principles for acetolysis presented by Fægri and Iversen (1989), mostly with the addition of *Lycopodium clavatum* tablets (Stockmarr 1971). The prepared pollen was dyed with basic fuchsine and mounted in glycerol on microscope slides.

The pollen sum excludes high-productive mire pollen taxa like Cyperaceae, Ericales and *Rubus chamaemorus*. Although, in many cases trees such as *Alnus incana* and *Betula pubescens*, and shrubs such as *Betula nana* and *Salix* species grow on peat, those taxa were included in the basal pollen sum.

Pollen analysis was mainly carried out under 400 × magnification.

At sites 6 and 7 (Table 1), a preliminary study on modern pollen deposition was carried out (Vorren 1993).

RADIOCARBON DATES

Thirty nine conventional radiocarbon dates are included in the present study (Table 3). Peat samples for radiocarbon dating were normally dissolved in 5% KOH by a slight heating and stirring, then washed through a 1 mm sieve. The fraction smaller than 1 mm was then sieved through a 0.063 mm mesh. If sufficient material was at hand, the intermediate fraction 1 – 0.063 mm was dated. This fraction is supposed to contain a concentration of moss leaves and particles. In some cases the fraction < 0.063 mm had to be added. For some samples (in the Austeinmyra series, Table 3) the humic fraction was extracted in the National Laboratory for ^{14}C-dating in Trondheim and dated: the A-samples. Low-humified *Sphagnum* peat (≤ H 3) was not sieved. Roots and rootlets were removed from these samples and they were bulk-dated. To get sufficient dating material a normal sample interval was 2 cm, but in some cases (low-humified peat) as much as 4 cm. The calibration of the dates is carried out at the laboratory in Trondheim. The present interpolations are linear, extracted from the calibrated time scales of the diagrams.

LITHO- AND CHEMOSTRATIGRAPHY

Peat humification of three sequences was analysed according to the colorimetric method of Overbeck, modified by Bahnson (Aaby 1986): site Nos. 6, 7, 8 and 10 (Table 1). In order to investigate the transition process to ombrogenic peat, Mg and Ca was measured for every cm at sites No. 6 and 7, Olsborgmyra. Samples of 20 cm^3 were dried for 24 hours by 105^oC and ignited for two hours by 600^oC. The cations were measured by means of an atomic absorption spectro-photometer at PLANTEFORSK, Holt, Tromsø, according to standard methods.

DIAGRAMS

The pollen diagrams were constructed by means of the programs TILIA 2.6.4 and TILIAGRAPH version 2.6 (cf. version 1.17: Grimm 1992). The vertical scales of the diagrams are linear time scales based on the calibrated radiocarbon ages given by the dating laboratories.

NOMENCLATURE

The nomenclature of the vascular plants is according to Lid and Lid (1994), bryophytes except sphagna: Nyholm (1993), Hallingbäck and Holmåsen (1985), sphagna: Frisvoll et al. 1995, hepatics: Arnell (1956), and lichens: Krog et al. 1980.

MIRE TERMINOLOGY

The terminology of mire is based on Sjörs (1950). Note that vegetation may be termed minerotrophic (nourished by ground water coming from the mineral ground) in contrast to the term ombrotrophic. Peat formed by a minerotrophic vegetation is termed geogenic. This refers to common use in mire literature in order to avoid expressions such as “minerogenic peat”. Ombrotrophic vegetation creates an ombrogenic peat.

RESULTS

Only five of the eight mires are represented by a pollen diagram here, visibly one from the coastal region, one from the fjord region, two from the inland region, and one from the interior highland.

Site 1: **Austeinmyra** (cf. Table 1)

The bog is situated slightly below the marine main line, here about 27 m a.s.l. (T. Vorren, pers. comm.). The name of the bog is not official, here named after the farm to which it belongs.

The bog is surrounded by low cliffs, which are covered by an *Empetrum nigrum* ssp. *hermaphroditum* heath vegetation. Scattered occurrences of low-growing birches and rowans occur in some places where pasturing is not intensive. The landscape is a typical strandflat with small islands and large areas of marine sediments, mainly covered with mires, heaths and cultivated grasslands.

The original morphology of the bog (before peat cutting and erosion) is not easy to determine. Today its low-lying part is dominated by moist *Eriophorum angustifolium-Sphagnum* vegetation, which represents the re-vegetation stage after an extensive peat cutting. Along the margins, banks of non-exploited peat exist, and in the western end of the bog is an ombrotrophic eccentric element, slightly eroded and dominated by island-formed hummocks. The coring was carried out from the crest of a hummock at a bank in the middle part of the mire, which according to the owner had not been exploited. The surface of the bank is hummocky, with 50–60 cm high hummocks separated by minor wet areas.

Lithostratigraphy:

0–107 cm	*Sphagnum*-Ericales peat with *Eriophorum vaginatum* layers (0–2950 BP); (0–3090 cal. BP). Sedimentation rate: 0.35 mm/cal. year
0–44 cm	Ericales peat (H 4, von Post's scale)
44–51 cm	*Sphagnum* peat (H4)
51–60 cm	*Eriophorum vaginatum* peat (H 4)
60–73 cm	*Sphagnum*-Ericales peat (H 6)
73–78 cm	*Eriophorum vaginatum* peat (H4)
78–90 cm	*Eriophorum vaginatum-Sphagnum* peat (H 4)
90–93 cm	Ericales peat (H 6)
93–107 cm	*Sphagnum* peat (H4)
107–168 cm	*Carex*-carr peat (2950–7700 BP); (3090–8800 cal. BP). Sedimentation rate: 0.11 mm/cal. year BP
> 168 cm	Sand

Note: Living roots down to ca. 70 cm.

The non-probable dates in the interval 65–50 cm (Table 3), indicate sedimentation disturbances there, probably caused by multi-gelation processes (cf. Vorren 1979a) at the base of the hummocks. Influx data indicate that the 65–41 cm interval (1400–1300 BP) should be excluded, and considered re-deposited or contaminated.

The first occurrences of apophytes have been recorded pollen-analytically at 4190 BP. They increase towards the present times, especially after 1070 BP. Due to the steady representation of minerotrophic taxa throughout the diagram, it is not easy to state a defined pollen-analytical level for the transition to ombrotrophic environments. However, the lithological changes at 107 cm (2950 BP) certainly mark a transition from mesotrophic to extremely oligotrophic peat.

Site 2: **Brensholmmyra** 1 (cf. Table 1, Fig. 2)

The coring site is positioned in the central part of Brensholmmyra, ca. 20 m east of a main road crossing the bog, and ca. 50 m south of a central road cross. The bog surface at the coring site is about 11 m a.s.l.

The gross morphology is that of a typical eccentric bog, though with a large area (mire element) of mesotrophic sedge fen communities bordering the ombrotrophic main element in the distal, eastern and northeastern part. The surrounding terrestrial vegetation is an open *Betula pubescens* heath woodland with low-growing birches. West of the mire complex there are cultivated and semi-cultivated grasslands and pastures. South of the bog, moisture-demanding carrs with tall-growing *Salix* species occur.

The detailed morphology of the bog is characterized by low and broad string-hummocks and elongate hollows dominated by *Trichophorum cespitosum* lawns. The vegetation is basically ombrotrophic. Due to shale sand drift from the roadsides, however, mesotrophic species may occur, such as *Tofieldia pusilla* in liverwort-*Sphagnum fuscum* vegetation and *Eriophorum angustifolium* and *Drepanocladus badius* in the *Trichophorum cespitosum*-*Sphagnum tenellum* hollows. The hummocks are characterized by *Racomitrium lanuginosum* and *Empetrum nigrum* ssp. *hermaphroditum*, with an admixture of *Calluna vulgaris* in the lower hummock level. The oceanic moss species *Dicranum leioneuron* occurs in hollows together with a cool-maritime feature when occurring in coastal bogs, the moss *Onchophorus wahlenbergii* (cf. Eurola & Vorren 1980).

Lithostratigraphy:

0–103 cm	*Sphagnum*-Ericales peat (0–2760 BP); (0–2870 cal. BP). Sedimentation rate: 0.36 mm/cal. year BP.
0–45 cm	*Racomitrium lanuginosum-Sphagnum fuscum-Calluna* peat
45–103 cm	*Sphagnum* peat with some Ericales remains
103–142 cm	*Carex*-carr peat (2760–3160 BP); (2870–3395 cal. BP). Sedimentation rate: 0.74 mm/cal. year BP
142–168 cm	*Carex-Betula-Equisetum* peat (3160–3440 BP); (3395–3685 cal. BP). Sedimentation rate: 0.74 mm/cal. year BP).
168–178 cm	Humus-sand layer (3440–3654 BP); (3685–4029 cal. BP)
> 178 cm	Shale sand

The core was retrieved from a low string hummock.

Pollen analysis indicates only sporadic human impact, due to the long distance to any cultivated ground and pastures. Only the charcoal curve may indicate a constant presence of man, except for a short period around 3200 BP.

Site 3: **Straumen, Rossfjord** (cf. Table 1)

The site is a raised, eccentric bog, about 170 × 100 m large (1.7 ha) lying on a marine ter-

Table 3. Radiocarbon dates of the present peat sequences

Lab. ref.	Sample name	Depth (cm)	Material dated	Date (± σ) (^{14}C-yr B.P.)	Calibrated date
			AUSTEINMYRA		
T-11954A	AUM 10–12	10–12	Peat	Recent	Recent
β-81876	AUM 34–36	34–36	Peat	1070 ± 60	AD 905–1020
T-12929	AUM 40–41	40–41	Peat	1320 ± 130	AD 620–800
T-11955A*	AUM 49–51	49–51	Peat	680 ± 60	AD 1295–1370
T-12131*	AUM 50–51	50–51	Peat	580 ± 65	AD 1340–1420
T-12391	AUM 64–66	64–66	Peat	1405 ± 55	AD 615–675
T-12392	AUM 86–88	86–88	Peat	2165 ± 80	BC 355–80
T-11956A	AUM 89–91	89–91	Peat	1975 ± 80	BC 45-AD 120
T-11957A	AUM 106–108	106–108	Peat	2950 ± 50	BC 1230–1050
T-11958A	AUM 132–134	132–134	Peat	4190 ± 115	BC 2910–2600
T-11959A	AUM 154–156	154–156	Peat	6395 ± 75	BC 5400–5265
			BRENSHOLMMYRA 1		
T-7548	BM I:1	7–10	Peat	Recent	Recent
T-7549	BM I:2	101–104	Peat	2760 ± 50	BC 980–860
T-7551	BM I:3	140–143	Peat	3160 ± 100	BC 1540–1350
			STRAUMEN		
T-5037	Straumen 1	9–12	Peat	730 ± 40	AD 1240 ±50
T-5038	Straumen 2	152.5–156	Peat	3760 ± 150	BC 2325 ±215
			MÅLSNES		
T-9417	Må 24–28	24–28	Peat	390 ± 60	AD 1440–1525
T-9418	Må 118–122	118–122	Peat	2965 ± 70	BC 1310–1075
T-9419	Må 174–178	174–178	Peat	3620 ± 70	BC 2120–1910
T-9420	Må 230–234	230–234	Peat	4635 ± 75	BC 3515–3340
			ASPMO		
T-6741	Aspmo 1	50–52	Peat	1910 ± 60	AD 20–140
T-6742	Aspmo 2	95–98	Peat	3190 ± 30	BC 1510–1430
T-6743	Aspmo 3	199–201	Peat	4910 ± 80	BC 3780–3640
			OLSBORGMYRA 2		
T-3667	O 4	25–28	Peat (Sph. l.)	1940 ± 50	AD 15 ±75
T-3666	O 3	58–61	Peat (Sph. l.)	2370 ± 80	BC 575 ±155
T-3665	O 1	96–99	Peat (Sph. l.)	2790 ± 80	BC 1025 ±125
			HUMMOCK OLSBORG		
T-6889	TueOL 1	51–53	Peat	1280 ± 60	AD 670–790
			SMEDRUD		
T-6427	Sme 2	114–116	Peat	3000 ± 80	BC 1310 ±140
T-8927	Sme 3	146–149	Peat (Sph.l.)	3355 ± 90	BC 1755–1540
T-8928	Sme 4	181–184	Peat (Carex)	3590 ± 90	BC 2065–1830
			FOSSLI		
T-6738	Fossli 1	14–16	Peat	1830 ± 60	AD 110–250
T-6739	Fossli 2	57–59	Peat	3190 ± 30	BC 1530–1320
T-6740	Fossli 3	122–124	Peat	4980 ± 90	BC 3980–3640
			VARDFJELLMYRA		
T-9832	VM 1	21–23	Peat	980 ± 35	AD 1005–1050
T-9833	VM 2	38–40	Peat	2590 ± 85	BC 840–765
T-10275	VM 3	81–83	Peat	4465 ± 115	BC 3350–2940
T-9834	VM4	111–113	Peat	4970 ± 45	BC 3810–3710
T-9835	VM 5	140–142	Peat	5415 ± 95	BC 4365–4170
T-9836	VM 6	222–224	Peat	6410 ± 105	BC 5470–5250

* Considered contaminated

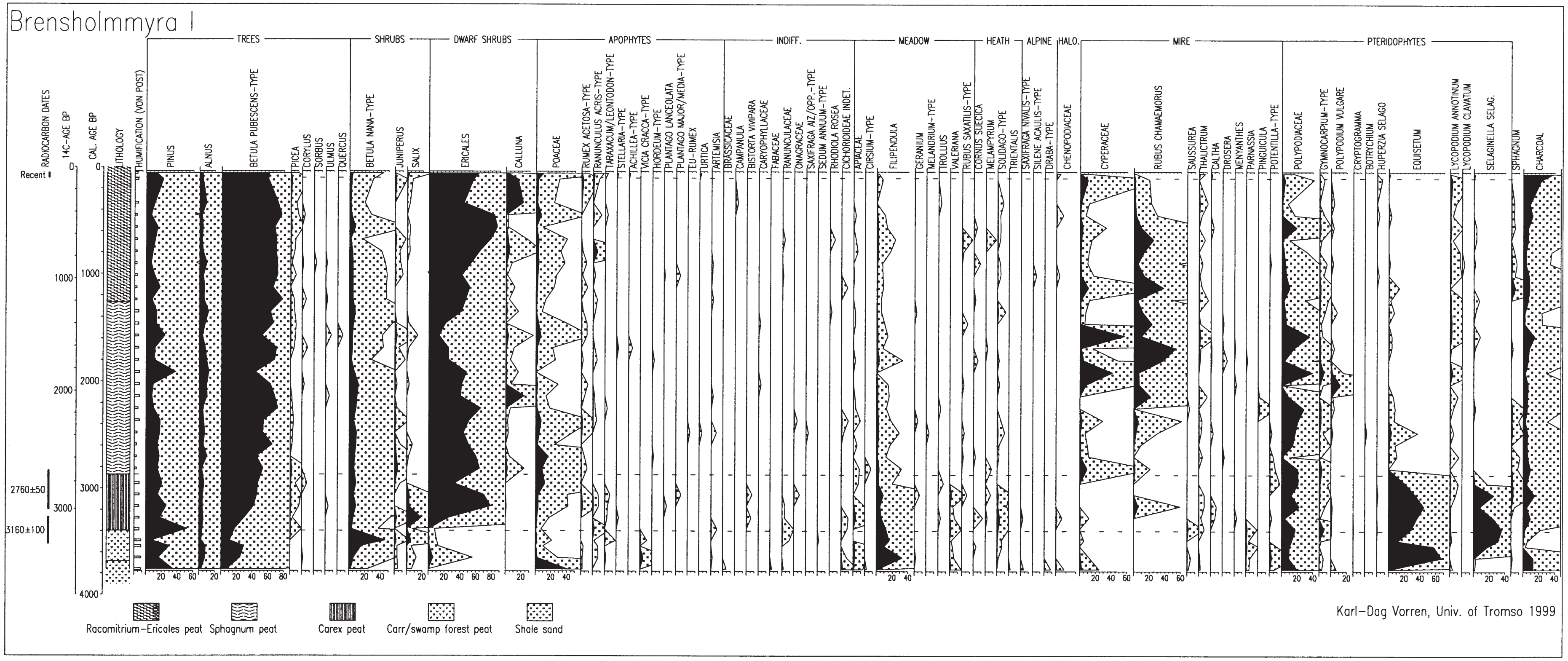

Fig. 2. Pollen diagram from Brensholmmyra, site 2, arranged according to a calibrated chronological scale (Y-axis)

race about 12 m a.s.l. at the stream outlet from the lake Rossfjordvatn (1 m a.s.l.). The area around the bog is a cultural landscape dominated by cultivated hay meadows and pastures in the more remote mountain slopes. A road cuts through the southern, distal edge of the bog.

The bog has been subject to peat cutting. Peat trenches dominate the proximal part of the bog. A lagg with *Calamagrostis purpurea, Carex canescens, Juncus filiformis, Cornus suecica, Betula pubescens, Salix glauca* a.o. encircles the proximal and lateral edges of the bog. A mosaic of *Calluna-Racomitrium* hummocks, *Sphagnum fuscum-Vaccinium microcarpum* hummocks and dry lawn hollows with *Trichophorum cespitosum* and much *Ptilidium ciliare* dominate the bog expanse.

The coring was carried out in the deepest part of the bog, i.e. a little south of the peat cutting area close to the centre of the bog. The sampled core was 156 cm long, slightly compressed.

Lithostratigraphy:

0–9 cm	*Trichophorum cespitosum*-Ericales peat (H 7) (?-700 BP); (?-650 cal. BP)
9–127 cm	*Sphagnum*-Ericales peat (H 3–5) (700–3190 BP); (650–3605 cal. BP)
127–132 cm	*Eriophorum vaginatum* peat (H 3–4) (3190–3295 BP); (3605–3730 cal. BP).
132–146 cm	*Carex* peat (H 5–6) (3295–3560 BP); (3730–4085cal. BP)
146–156 cm	*Carex-Betula* peat (3560–3760 BP); (4085–4525 cal. BP)
> 156 cm	Sand

Note: Sedimentation rate between 650 and 4525 cal. BP: 0.38 mm/cal. year.

The pollen record indicates a transition to ombrogenic peat between 3000 and 2900 BP (interpolated). This date is based on the expansion of *Calluna*, other Ericales, *Rubus chamaemorus* and *Sphagnum*, and the decrease of *Cornus* and Polypodiaceae. The uppermost peat is oxidized and eroded. A date of the start of agricultural impact in the surroundings gave 730 ± 90 BP. The occurrences of *Urtica* and a higher charcoal curve between 3000 and 2000 BP (interpolated) may indicate that there was a presence of man in the close environments in that actual period, but no open grasslands and meadows.

Site 4: **Målsnes** (cf. Table 1, Fig. 3)

The Målsnes bog is situated in a saddle position on a peninsula at the head of the Malangen fjord about 45 m a.s.l. A road crosses the bog at its lateral southwestern side and a football field has been established at the proximal, southern edge of the bog. To the west there are cultivated meadows and in the other directions a *Betula pubescens-Vaccinium myrtillus-Cornus suecica* woodland dominates.

The bog is eccentric with a raised proximal margin. Its central plane is probably eroded. The hollows are large, and the hollow-hummock pattern is diffuse. Hummocks are mainly low.

The hummock vegetation is dominated by *Calluna vulgaris*. Other important vascular plants on the hummocks are *Rubus chamaemorus, Eriophorum vaginatum, Drosera rotundifolia, Vaccinium microcarpum, V. vitis-idaea, V. myrtillus, V. uliginosum* and some scattered *Betula nana*. *Sphagnum fuscum* and *S. capillifolium* are the main hummock builders. On drier hummocks *Pleurozium schreberi, Cladonia mitis* and *C. rangiferina* are characteristic. Scattered, small *Betula pubescens* and *Pinus sylvestris* individuals (0.1–2 m) occur on the bog plain. The hollows are dominated by a *Trichophorum cespitosum-Sphagnum tenellum* community with an admixture of *Drepanocladus fluitans, Sphagnum lindbergii, S. balticum* and *Gymnocolea inflata*.

The core was sampled near the proximal margin of the bog, where the surface did not exhibit any erosional features, and the peat depth was 3 m. The compressed core was 2.92 m. Birch logs occurred at 2 and 1 m depth below surface.

Lithostratigraphy:

0–178 cm	*Sphagnum* peat (H 3–5). Ericaceous horizons 91–109, 123–129, 158–168 cm. (0–3660 BP); (0–4025 cal. BP). Sedimentation rate 0.44 mm/cal. year BP
178–184 cm	Ericales-*Sphagnum* peat (H 5), with *Betula pubescens* macrofossils (3660–3790 BP); (4025–4200 cal. BP). Sedimentation rate: 0.34 mm/cal.year BP
184–212 cm	*Sphagnum*-Ericales peat (H 4). (3790–4380 BP); (4200–5065 cal. BP). Sedimentation rate: 0.32 mm/cal. year
212–262 cm	*Carex* carr peat (H 6–8) (4380–5440 BP); (5025–6500 cal. BP). Sedimentation rate: 0.34 mm/cal. year

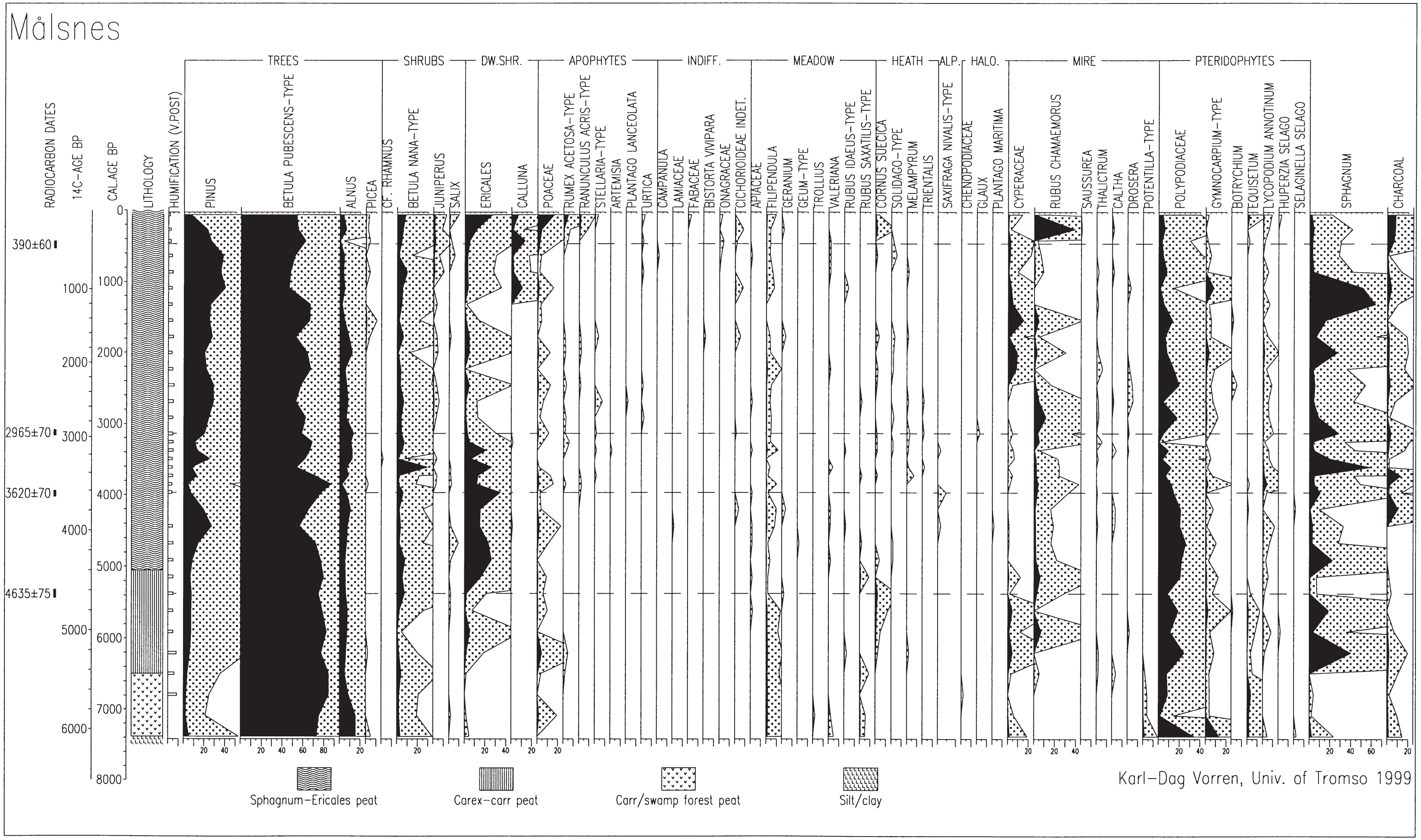

Fig. 3. Pollen diagram from the bog at Målsnes, site 4, arranged according to a calibrated chronological scale (Y-axis)

262–292 cm	Swamp forest peat (H 8–9) (5440–6070 BP); (6500–7380 cal. BP). Sedimentation rate: 0.34 mm/cal. year
> 292 cm	Silt/clay

Note: The lithological geogenic/ombrogenic transition occurs at 212 cm (ca. 4380 BP).

Pollen evidence shows that a locally wet phase with much Cyperaceae and less Ericales took place about 2500 to 1100 BP. Since 1100 BP *Calluna vulgaris* played a prominent part in the vegetation.

Man's impact is weak. Possible traces of a semi-permanent settlement are seen in the start of the *Juniperus* and *Ranunculus acris* curves, increase in the charcoal curve and the decreasing Polypodiaceae curve about 3600 BP. The establishment of open pastures and meadows occurred around 390 BP (AD 1440–1525).

Site 5: **Aspmo** (cf. Table 1)

The Aspmo bog (ca. 25 m a.s.l.) is situated at the abandoned farm of Aspmo at the Målselv river. The closest surroundings are hills covered with grass and birch vegetation. A road is established at the northern lateral margin of the bog, and stands of deciduous trees occur along the distal margin and each of the lateral margins. A grassy slope (pasture) borders the proximal margin.

The bog is eccentric ombrogenic, with a subsided central plain (indicating former erosion) where high string hummocks and elongate hollows occur. The proximal, marginal slope is about 20 m broad, with an even surface where some juvenile pines grow.

Coring was carried out 15 m from the proximal mire margin to avoid areas that had been eroded.

Lithostratigraphy:

0–10 cm	Low-humified hummock peat (0–400 BP); (0–370 cal. BP). Sedimentation rate: 0.27 mm/cal. year
10–20 cm	*Eriophorum vaginatum* peat (400–700 BP); (370–740 cal. BP). Sedimentation rate: 0.27 mm/cal. year
20–99 cm	*Sphagnum* peat (H 3–5.5) (700–3230 BP); (700–3470 cal. BP). Sedimentation rate: 0.26 mm/cal. year
99–180.5 cm	*Sphagnum-Carex* peat (H 3.5–7) (3230–4550 BP); (3470–5155 cal. BP). Sedimentation rate: 0.48 mm/cal. year
180.5–192 cm	Magnocaricetum peat (H 7) (4550–4780 BP); (5155–5860 cal. BP). Sedimentation rate: 0.57 mm/cal. year
192–230 cm	*Carex*-carr/swamp forest peat (H 8) (4780–5410 BP); (5360–6130 cal. BP). Sedimentation rate: 0.49 mm/cal. year
230–240 cm	Moss-rich peat with deciduous tree remains (H 4) (5410–5580 BP); (6130–6330 cal. BP). Sedimentation rate: 0.55 mm/cal. year BP
240–243 cm	Mineral-rich Amblystegiaceae peat (5580–5590 BP); (6330–6385 cal. BP). Sedimentation rate: 0.55 mm/cal. BP
> 243 cm	Stiff silty clay

Note: Living roots to 1 m, some down to 1.5 m.

Palynological indications of a shift from minerotrophic environments (Cyperaceae-*Equisetum* vegetation) to ombrotrophic environments (Ericales-*Rubus chamaemorus-Calluna* vegetation) is interpolated to 2750 BP.

High charcoal percentages occur between 3700 and 3400 BP suggesting the proximity of man, but no agricultural traces. Between 2200 and 1800 BP there is a break in the otherwise continuous charcoal curve. Establishment of open pastures and meadows start at a chronological level, which may coincide with that of the Målsnes site.

Sites 6 and 7: **Olsborgmyra 2** and **Hummock Olsborg** (cf. Table 1, Figs 4–6)

The name Olsborgmyra (33 m a.s.l.) has been introduced by Vorren (1993) for the northernmost sub-complex of Stormyra near Olsborg, Målselv. To the west, a rather pure pine forest prevails on the sandy river terraces. To the east, on clayey deposits, there is deciduous woodland dominated by birch, but with extensive *Alnus incana* stands. To the south, an equally large ombrotrophic bog subcomplex is situated and between the two subcomplexes there is an open *Carex lasiocarpa* minerotrophic mire which gradually transgresses into a *Betula pubescens-Alnus incana-Salix pentandra-S. nigra* carr towards the proximal spring horizons in the east.

Farms and village occur 1–1.5 km distant in the southwest and 0.6 km to the east. A little village is recently established ca. 0.6 km to the west of the sampling site.

A description of the gross morphology, small relief, and vegetation of the bog and the close environments is given by Vorren (1993). In summary, the bog has an eccentric, ombrogenic morphology, with markedly raised

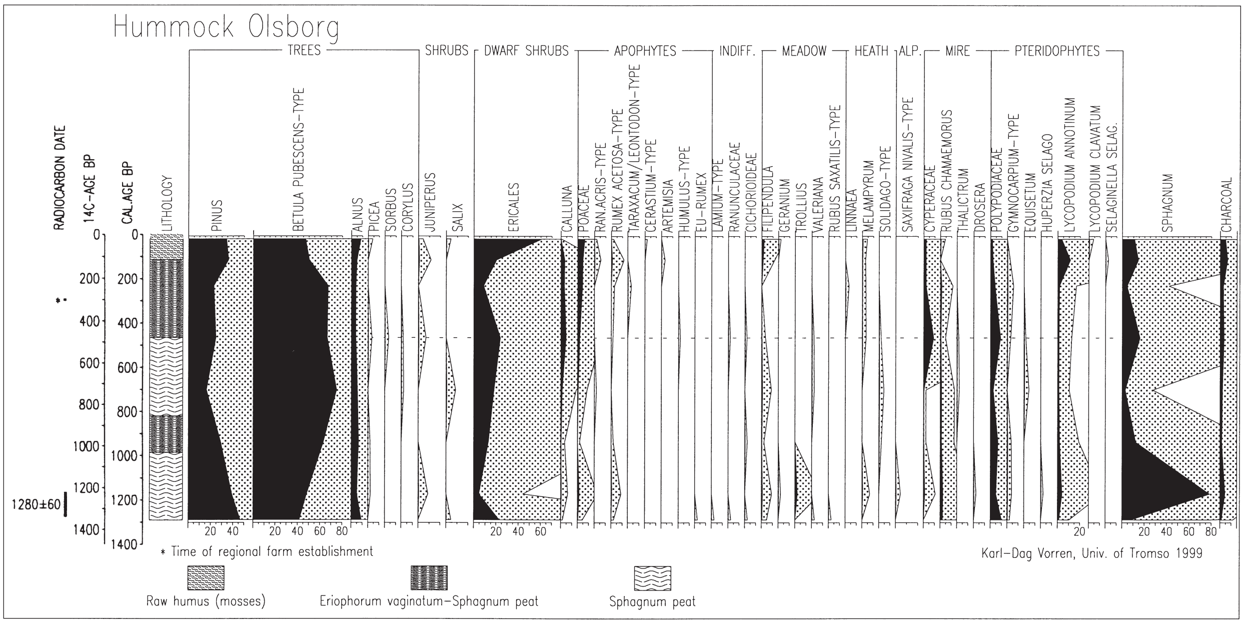

Fig. 4. Pollen diagram from a hummock at Stormyra, Olsborg, site 6, arranged according to a preliminary time scale. There may be a hiatus above the radiocarbon date at the hummock base

marginal slopes at its northern and western margins. It was originally supplied with ground water from its present distal margin in the southeast. During the Sub-Atlantic period it formed an independent ombrogenic hydrology with a height centre at its northwestern margin. The bog expanse has subsided due to erosion, and large, wet mud-bottom hollows dominate the central part. The hummocks in the central part reach heights of about 60 cm. Pine trees grow at the proximal margin, and stunted pines up to 5 m high grow on the hummocks of the bog expanse.

The hummock profile, Hummock Olsborg, 1280 (?) – 0 BP (Fig. 4)

Through the crest of a ca. 60 cm high hummock a compressed peat core of 55 cm was sampled, the non-compressed depth of the peat being about 70 cm.

Lithostratigraphy:

0–5 cm	Raw humus (mosses) (H 3–5)
5–10 cm	*Sphagnum fuscum* peat (H 4)
10–20 cm	Ericales-*Eriophorum vaginatum-Sphagnum fuscum- S. lindbergii* peat (H 6–7)
20–35 cm	*Sphagnum lindbergii* peat (H 3.5–7)
35–42 cm	*Sphagnum fuscum*-Ericales peat (H 4–6)
42–53 cm	Mixed *Sphagnum fuscum-S. lindbergii* peat (H 4)
53–55 cm	*Sphagnum lindbergii* peat (H 7–9)

Note: Supposed no hiatus, the mean sedimentation rate above 52 cm (compressed) is: 0.43 mm/cal. year BP.

The macrofossils indicate that the hummock stratigraphy has an intermediate layer (20–35 cm) of hollow peat (Fig. 5). Below and above this layer is a *Sphagnum fuscum* hummock peat. Near the basis of the profile, ca. 53–45 cm below surface in the compressed core is a hiatus-like change of humification values and dry density. A ^{14}C-date at 51–53 cm gave 1280 ± 60 BP (AD 670–790). The low dry density interval between 53 and 45 cm might indicate a loosening of peat by soil frost movements (multigelation, cryoturbation, cf. Vorren 1972, 1979a). Such loose peat as the one in the 53–45 cm interval occurs in mud-bottoms. It constitutes a mixture of hollow peat with macrofossils of *Sphagnum lindbergii*, *S. balticum* and *S. tenellum*, and low hummock peat with *Sphagnum fuscum*. It is therefore possible that this level is synchronous with, or a little metachronous to the uppermost levels in the hollow profile (Olsborg 2), which is also a mudbottom peat. The central *Sphagnum lindbergii* layer in the hummock profile may be explained by: 1) upheaval of hollow peat caused by lateral soil frost pressure in the adjacent hollows, or 2) being a remnant of a former, eroded bog level, conserved in the hummock.

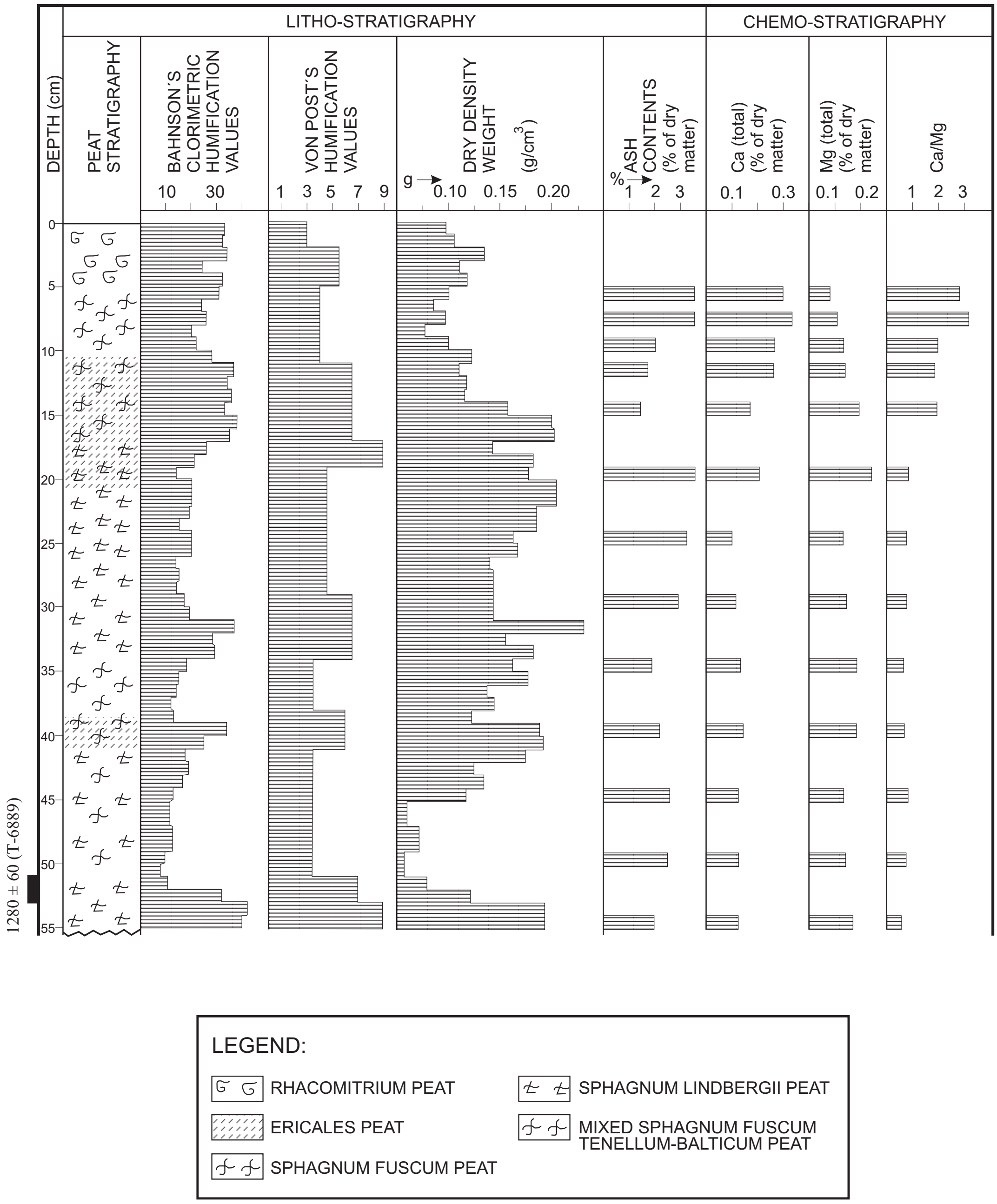

Fig. 5. Humification and chemistry of the Hummock Olsborg profile

An estimation of the age of the start of the hummock formation based solely on the historically recognized date of farm establishments (1788) in the surroundings is possible. The start of the agricultural expansion is reflected in the pollen diagram at 14 cm below surface. An extrapolation gives an age of approximately 500 cal. BP for the possible hiatus at 53–45 cm below surface. However, considering the consolidation and humification degrees of the pre-farming peat in the 14–45 cm interval, the radiocarbon date, 1280 BP, seems acceptable.

A comparison between the colorimetric and the ocular/manual v. Post humification degrees of the Olsborg hummock profile is seen in Fig. 8. The humification peaks have been recognized by both methods.

The hollow profile, Olsborgmyra 2, ca. 3065–1600 BP (Fig. 6)

Cored sections of the 400 × 500 m large bog show that the peat depth is about 1.5–2 m. A shallow, basal *Carex* and carr peat, is overlain by an about 1.5 m thick, more or less om-

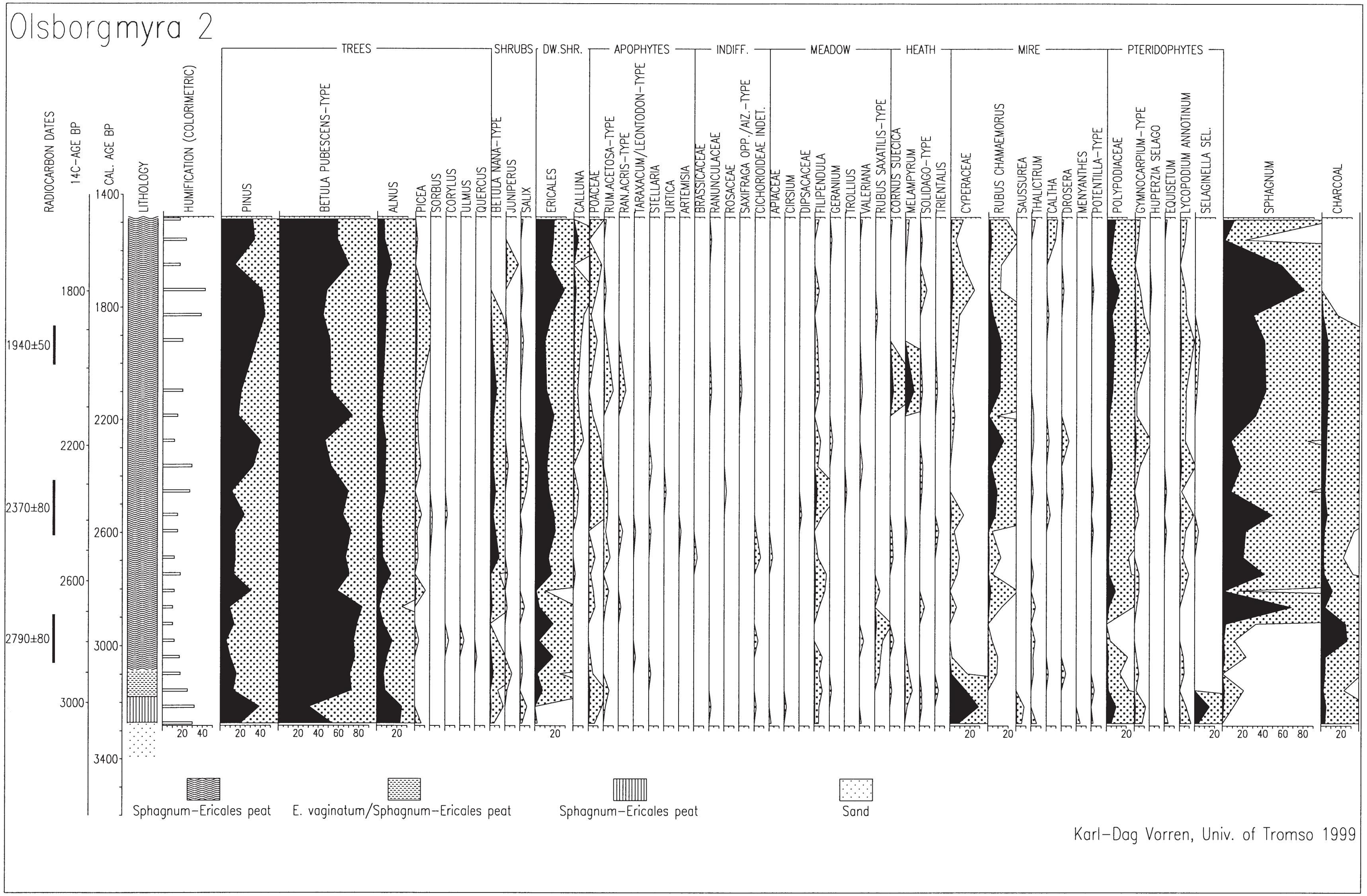

Fig. 6. Pollen diagram from a hollow at Stormyra, Olsborgmyra 2, site 7, arranged according to a calibrated chronological scale (Y-axis)

brogenic *Sphagnum lindbergii*-dominated peat. The compressed 1.23 m deep peat sequence was sampled in a *Trichophorum cespitosum* lawn of a hollow about 75 m from the proximal marginal slope at the northwestern end of the mire.

Lithostratigraphy:

0–107 cm	*Sphagnum*-Ericales peat (1600 ?–2895 BP) (1450 ?–3085 cal. BP)
0–95 cm	*Sphagnum lindbergii* peat (H 3) (1600–2765 BP) (1450–2945 cal. BP). Sedimentation rate: 0.63 mm/cal. year
95–107 cm	*Eriophorum vaginatum*-*Sphagnum* peat (H 4) (2765-2895 BP) (2950–3085 cal. BP). Sedimentation rate: 0.86 mm/cal. year
107–115 cm	*Eriophorum vaginatum*-*Sphagnum*-Ericales peat (H 5) (2895–2980 BP) (3085–3180 cal. BP). Sedimentation rate: 0.84 mm/cal. year
115–123 cm	*Sphagnum*-*Carex* peat (H 7) (2980–3065 BP) (3180–3270 cal. BP). Sedimentation rate: 0.89 mm/cal. year
> 123 cm	Sand

The paludification at the time of the start of rapid growth (ca. 2800 BP) was extensive on the forested terrace, and led to a marked decrease of the pine stands. Pine pollen influx during the time interval ca. 2800 to 2350 BP was as low as 50–150 pollen grains cm^{-2} $year^{-1}$, which indicates a regional decline of the pine forests in the northernmost part of the Målselv valley and its lateral valleys.

The Ca/Mg ratio of the hollow sequence decreases to below 2.0 about 2790 BP and to about 1.0 at 2400–2300 BP (Fig. 7). The Ca/Mg ratio of the hummock peat (see upper part of Fig. 7) is mainly below 1.0, except in the uppermost peat layer, deposited after the establishment of farms in the remote surroundings, after which there is an increase to about 3.0. This is due to an increase in Ca and a contemporary decrease in Mg. The increase in Ca may partly be due to a concentration of the Ca capital of the peat in the living vegetation. The decrease of Mg is hard to explain. The ash content of the peat sequence is low. Since about 2500 BP it was below 4%.

The colorimetric humification degrees are low in both the hollow and hummock profiles (Fig. 7) The lowest humification values occur about 2600–2500 BP (interpolated). Higher humification value intervals occur about 2400, 2150 and 1850–1750 BP.

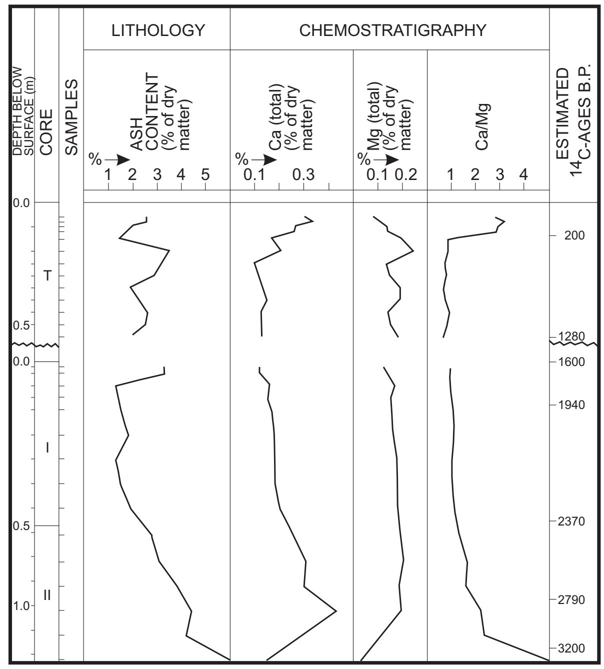

Fig. 7. Humification and chemistry of a joint hummock + hollow profile from Olsborgmyra 2 and Hummock Olsborg (sites 6 and 7)

Site 8: **Smedrud, Fosshaug** (the Bjørndalsmyra) (cf. Table 1, Fig. 8)

A core was retrieved from the proximal part of Bjørndalsmyra, an eccentric ombrogenic bog where the easternmost ombrogenic occurrences of *Calluna* in the Målselvdalen valley are noted. The bog is situated near the river fall of Målselvfossen. Pine forests dominate the river terraces, and birch dominates on the mesic slopes near the farm sites. Grey alder occurs abundantly at the ravines in the clay sediments and as a gallery forest along the Målselv river.

The vegetation of the sampling area is characterized by *Empetrum nigrum* ssp. *hermaphroditum*, *Vaccinium uliginosum*, *Rubus chamaemorus* with an admixture of *Calluna vulgaris*, *Andromeda polifolia*, *Vaccinium microcarpum*, *Drosera rotundifolia* and *Eriophorum vaginatum*. The cryptogam layer is dominated by *Sphagnum fuscum*. *Cladonia rangiferina* is frequent. *Racomitrium lanuginosum* occurs sparsely.

The proximal margin is constituted by a *lagg* with a swamp forest characterized by: *Alnus incana*, *Betula pubescens*, *Caltha palustris*, *Epilobium angustifolium*, *Equisetum arvense*, *Filipendula ulmaria*, *Galium palustre*, *Geum rivale*, *Gymnocarpium dryopteris*, *Paris*

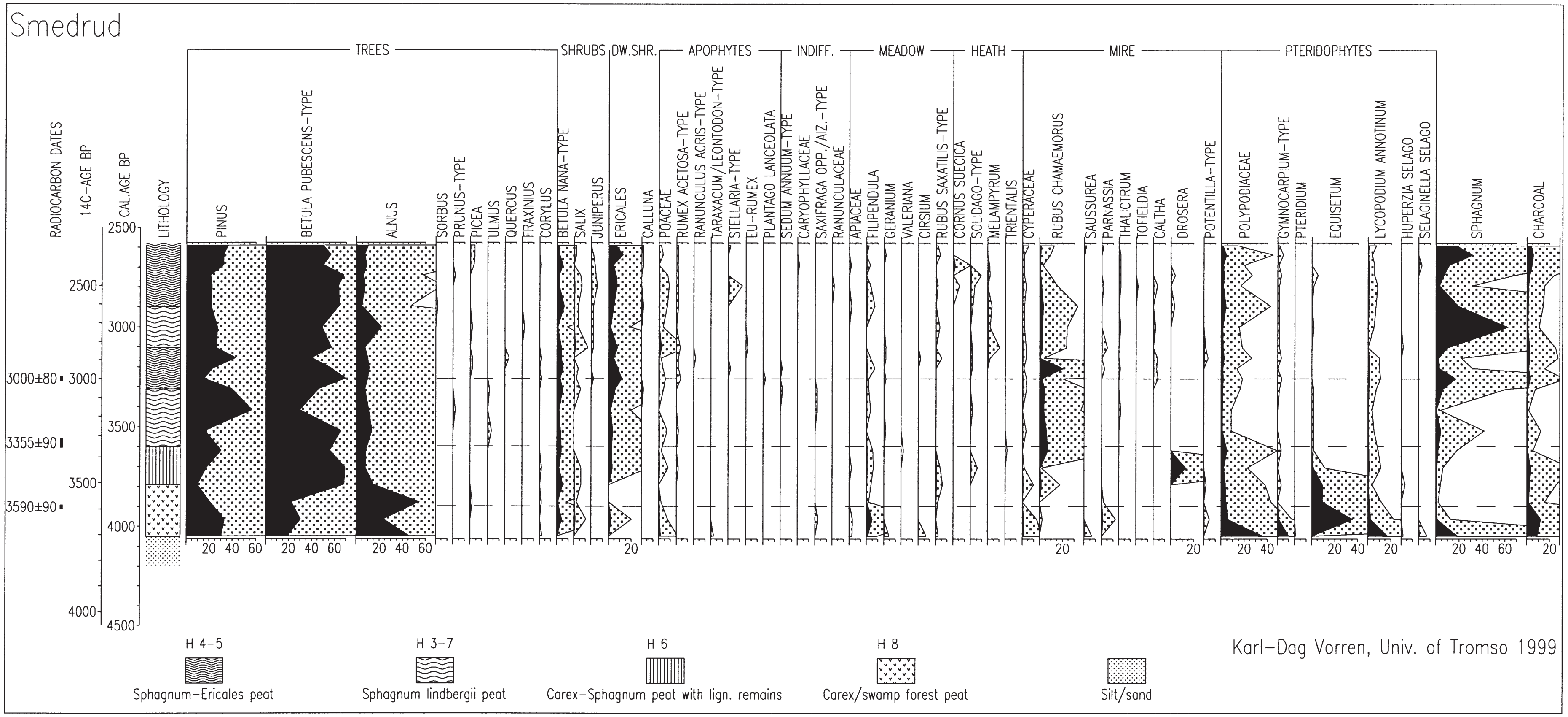

Fig. 8. Pollen diagram from Smedrud, Fosshaug, Bjørndalsmyra, site 8, arranged according to a calibrated chronological scale (Y-axis)

quadrifolia, Potentilla palustris, Viola palustris, Calliergon cordifolium, C. richardsonii, Plagiomnium ellipticum.

The sampling site is ca. 70 m south of the Smedrud field area, where the peat thickness varies between 2 and 3 m.

Lithostratigraphy:

50–148 cm	*Sphagnum*-Ericales peat (2150–3355 BP); (2145–3600 cal. BP). Sedimentation rate: 0.67 mm/cal. year
50–86 cm	*Sphagnum*-Ericales peat (H 4–5, layered) (2150–2615 BP); (2145–2682 cal. BP)
86–100 cm	*Sphagnum* peat (H 3) (2515–2795 BP); (2680–2890 cal. BP)
100–120 cm	*Sphagnum*-Ericales (H 3–7, layered) (2795–3055 BP); (2890–3190 cal. BP)
120–148 cm	*Sphagnum* peat (H 3) (3055–3355 BP); (3190–3600 cal. BP)
148–170 cm	*Carex-Sphagnum* peat with ligneous remains (H 6) (3355–3505 BP); (3600–3790 cal. BP). Sedimentation rate: 1.15 mm/cal. year
170–201 cm	Carr/swamp forest peat, the lowermost 3 cm with sand lenses. (H 8) (3505–3715 BP); (3790–4060 cal. BP). Sedimentation rate: 1.15 mm/cal. year
> 201 cm	Gradual transition from silt/sand-rich humus to silt/sand at ca. 210 cm

Note: The present core (FO 1, 50–201 cm below surface, compressed) was retrieved in July 1985 below a still existing soil frost layer 30–50 cm below surface.

Peat and pollen and spore stratigraphy suggests that the bog originated from a swamp forest dominated by grey alder, which was replaced by a *Carex-Sphagnum-Rubus chamaemorus* vegetation. The latter changed to an ombrotrophic *Sphagnum*-Ericales vegetation about 3355 BP. At the interpolated 3200 BP chronological level of the core, the lowest humification values of the peat profile are found (cf. Vorren et al. 1993). Also between ca. 2800 and 2500 BP (extrapolated) a low-humification peat interval occurs.

Site 9: **Fossli** (cf. Table 1)

The Fossli mire site is positioned close to the western side of the farm, about 1 km distant from the Smedrud site (8). The Fossli mire is a small and narrow, sloping eu-mesotrophic sedge mire, bordered by swamp forest and shrub mire communities. The core was sampled in the central, open area of the mire, in a flark (cf. Sjörs 1950) dominated by *Scorpidium scorpioides.*

Lithostratigraphy:

0–9 cm	*Scorpidium* flark peat (partly living mosses) (H 4)
9–112 cm	*Carex* peat (H 4–6) (1660–4680 BP); (1680–5360 cal. BP). Sedimentation rate: 0.28 mm/cal. year
112–124 cm	Carr-Ericales peat (H 7) (4680–5000 BP); (5360–5800 cal. BP). Sedimentation rate: 0.25 mm/cal. BP
124–175 cm	Swamp forest peat (H 8) (5000–6395 BP); (5800–7720 cal. BP). Sedimentation rate: 0.25 mm/cal. BP
> 175 cm	Silt

Note: Humification shift from H 6 to H4.5 at 47 cm below surface may be interpolated at 2830 BP (2975 cal. BP). *Menyanthes* seeds occur at the following levels below surface: 2, 108.5, 113.5, 118.5, 124.5 cm. True peat depth is 210 cm, which implies 35 cm compression.

Based on the regular deposition rates throughout the profile it is reasonable to believe that it has been affected by erosion. The hiatus probably occurs at 10 cm and should be dated at ca. 1600 BP.

The lowermost 20 cm of the 175 cm long peat profile has not been pollen-analysed. The pollen stratigraphy of the upper 155 cm shows that alder dominated with more than 50% up to ca. 5090 BP. After a temporary recovery it declined about 4200 BP (interpolated) and its representation fell to a level about 10%. The alder decline was followed by an increase in the Cyperaceae curve, which marked the final transition to an open *Carex* fen.

Site 10: **Vardfjellmyra** (cf. Table 1, Fig. 9)

The Vardfjellmyra is situated at 365 m a.s.l., which at this position means in the lower part of the sub-alpine birch belt, above the altitudinal limit of the mixed pine-birch forest (300 m here).

The bog is situated at a plateau about 50 m north of steep, 30–50 m high cliff wall. It is about 100 × 70 m large, and ombrogenic with a 0.6 m high marginal slope. The bog expanse is level with 0.5–1 m high isle-formed hummocks. High hummocks are covered with *Pleurozium schreberi* and *Cladonia mitis, C. rangiferina* and *Cladonia* spp. Low hummocks are dominated by *Sphagnum fuscum* and *Rubus chamaemorus*. The dwarf shrubs *Empetrum*

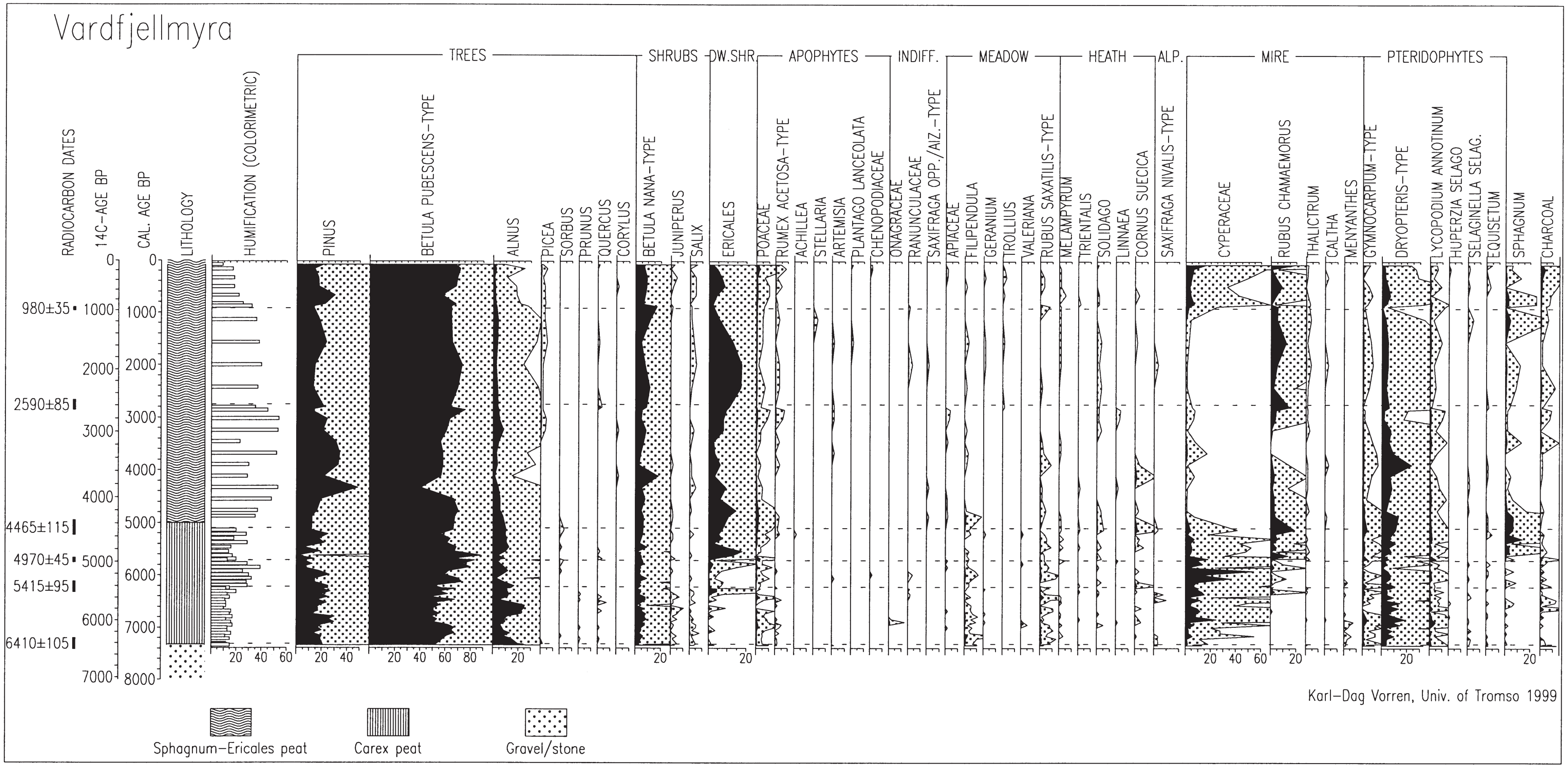

Fig. 9. Pollen diagram from a sub-alpine bog at Vardfjell, central part of the valley of Målselvdalen, site 10, arranged according to a calibrated chronological scale (Y-axis)

nigrum ssp. *hermaphroditum*, *Vaccinium myrtillus*, *V. uliginosum*, *Andromeda polifolia* and *Vaccinium microcarpum* are characteristic hummock species. At the bog margin *Betula nana* is abundant. The comparatively dry hollows are characterized by *Trichophorum cespitosum*, *Ptilidium ciliare*, *Sphagnum lindbergii*, *S. tenellum*, *Drepanocladus fluitans* and species which are common in the low hummocks, such as *Vaccinium microcarpum* and *Andromeda polifolia*.

The 225 cm long peat core from the centre of the bog was characterized by three major peat layers with transitional intervals.

Lithostratigraphy:

0–83 cm	*Sphagnum*-Ericales peat (0–4465 BP); (0–5095 cal. BP). Sedimentation rate: 0.2 mm/cal. year
83–141 cm	*Carex-Sphagnum*-Ericales peat (4465–4970 BP); (5095–5710 cal. BP). Sedimentation rate: 0.2 mm/cal. year
141–225 cm	*Carex* peat (4970–6425 BP); (5710–7320 cal. BP). Sedimentation rate: 0.57–0.75 mm/cal. year
141–155 cm	*Carex*-Amblystegiaceae-Ericales peat. Tree remains at 141–145 cm, ericaceous remains at 141–155 cm. (4970–5585 BP); (5710–6400 cal. BP)
155–225 cm	*Carex-Drepanocladus-Scorpidium* peat (5585–6425 BP); (6400–7320 cal. BP)
> 225 cm	Gravel and stones

Note: Humification shifts from high to low: Around 4970, 4465, 3750, 3300, 2590 and 1150 BP.

Colorimetric humification analyses (Vorren et al. 1996) show that the lowermost *Carex* peat is comparatively low-humified, whereas the humification values of the Ericales-*Sphagnum* peat are generally high. The humification decline between ca. 5000 and 4500 BP seems to indicate the most severe climate depression of the entire sequence. However, it is obviously a problem for the relative comparison of the humification values that the dominance of Ericaceae + Sphagnaceae, respectively Cyperaceae + Amblystegiaceae in the peat causes such great differences in the general humification values of the main peat layers.

The uppermost 98 cm (every cm) of the peat sequence have been combusted for calculation of loss-on-ignition. There is no marked change in the loss-on-ignition levels between ombrogenic and geogenic peat. On the contrary, the ignition residual increases slightly towards the top of the profile, especially after ca. 980 BP. This feature is obviously related to an increasing admixture of allogenic mineral grains. Expanding alpine environments with bare soil patches in the winter might be a source from where such minerals could be blown in together with snow and ice fragments.

The three main peat layers seemingly represent steps of oligotrophication, which took place about 5415 and 4465 BP, respectively. However, when considering the level of expansion of the most important indicators of oligotrophy – *Sphagnum* spores, and pollen of *Rubus chamaemorus* and Ericales – they all expand in the middle of the intermediate layer, ca. 5000 BP. Thus the biostratigraphy (pollen- and spore evidence) more points to a bi-partition of the stratigraphy, a basal geogenic peat and an upper, mainly ombrogenic peat.

DISCUSSION

REGIONAL FEATURES OF MIRE DEVELOPMENT

All bogs of the regional mire section II (sites 1–8) have in common the following development: 1) a basal carr or swamp forest peat (sites 6+7 have a basal *Carex*-*Sphagnum* peak, but the *Alnus* peak indicates close presence of an alder carr). 2) an intermediate Cyperaceae-Amblystegiaceae or Cyperaceae-*Sphagnum* peat. 3) an upper Ericales-*Sphagnum* peat.

The basal peat in the fjord and valley region is characterized by *Alnus incana* (cf. plant list of the “lagg” at site 8), at the coast mainly by birch. Transition from carr or swamp forest peat may be represented by a shrub-dwarf-shrub peat, representing an oligotrophication and probably a ground water lowering (site 9), or it may be characterized by a moisture-demanding Cyperaceae peat (in most cases). The ability of the *Sphagnum lindbergii* carpet vegetation for rapid peat accumulation (e.g. sites 7 and 8, ca. 1mm/year) is important in the oligotrophication process, but is dependent on basal ericaceous or *Eriophorum vaginatum* peat layers having created sufficiently acid conditions for formation of hollow vegetation. Successional ways of the regional mire vegetation units are suggested by Vorren et al. (1999).

THE GEOGENIC/OMBROGENIC PEAT TRANSITION

According to Mörnsjö (1968) a Ca/Mg ratio of #1.0 is characteristic of ombrotrophic conditions. This relationship varies, however. In Namdalen, Middle Norway, Vorren (1979b) investigated this ratio in ombrotrophic *Racomitrium lanuginosum* samples along a west to east transect (coast to the Swedish border). In the precipitation-rich, oceanic areas the ratio was 0.3–0.8, and in the more continental, low-precipitation area in the east 0.7–1.9.

Considering the evidence from Olsborgmyra (sites 6 and 7), the seemingly ombrogenic *Sphagnum lindbergii* peat deposited since 2790 BP marks a transition from mesotrophic to extremely oligotrophic environments. This is supported by pollen and spore evidence such as decline of Cyperaceae and increase of *Sphagnum*. However, the maximal expansion of Ericales p.p. and *Rubus chamaemorus* did not occur until about 2400 BP. *Calluna* occurred sparsely from this level. This is also the level where the Ca/Mg ratio declined to about 1. The Ca/Mg ratio of the hummock is steadily below 1, which confirms the expectation of a ratio below 1 as indicating ombrotrophy of vegetation. It thus seems that the final transition to ombrogenic environments at Olsborgmyra should be estimated at about 2400 BP, as a result of a process triggered about 2790 BP.

The lithological changes in peat are visible as changes in decomposition, which reflects changes in colour and texture of dominating macro-remains. Especially the "recurrence surfaces" (RY's) (Granlund 1932) are visual features in a dominating ombrogenic Ericales-*Sphagnum* peat. They represent the transition from dark Ericales-dominated peat to a rather pure, light *Sphagnum* peat over an entire bog surface. It must be emphasized that the concept of "recurrence surfaces" was discredited by the radiocarbon dating carried out by Lundqvist (1967). Since, in the present study, only one real "recurrence surface" has been localized throughout extensive transects, but only dated locally (Olsborgmyra, cf. site 7), the concept of "recurrence surface" (RY), is here designating marked local changes in the investigated peat profiles only. According to the "Phasic Theory" of bog growth (Barber 1981), raised bog growth is controlled above all by climate, even down to the level of the relative areas of hummock and pool (hollow), and the phase-shifts in peat growth are a result of climatic shifts. It is evident from my observations on recent vegetation that cryptogams forming hydrophilous communities (carpets), such as *Sphagnum lindbergii*, *S. majus* and *S. balticum* (Vorren et al. 1999), respond quickly to a climatically caused rise of the groundwater level. The vascular plants, having roots penetrating down into the geogenic nutrient-rich peat, will be able to persist for still some time in a mainly ombrotrophic environment (such as in the *Carex rostrata*-*Sphagnum lindbergii*-*S. majus* community of Vorren et al. 1999). Thus the visual, lithostratographic changes in peat caused by the "recurrence surfaces" of light, low-humified Sphagna Cuspidata peat are more likely to reflect the accurate time of climatic change than the changes of pollen assemblages which denote a gradual transition to ombrotrophic environments.

Calluna vulgaris is a characteristic, although not dominant plant of the central plain at the actual bogs. The *Calluna* pollen curves start at different times in the individual bogs (Table 4), and never exhibit really high percentages in this region, normally below 20. It is reason to believe that the spread of *Calluna* pollen is local, and that it reflects mainly a local bog expanse environment towards a differentiation in hummocks and hollows, at least since ca. 2750 BP. In such a context, the continuous occurrence of *Calluna* is an import-

Table 4. Date of first occurrence and continuous occurrence of *Calluna vulgaris*, and maximal percentage of *Calluna* in the respective pollen assemblages in the studied *Calluna-Racomitrium* bogs

Site:	Austein-myra	Brensholm-myra	Straumen	Målsnes	Aspmo	Olsborg-myra	Smedrud
Continuous occurrence from year BP	2100	2760	3100	1100	2750	2400	1350
First occurrence year BP	6000	3000	3000	4000	2750	2600	2750
Highest percentage	1	20	3	20	10	5	8

ant marker of the formation and persistence of ombrotrophic environments at the bog expanse together with other Ericales species (*Andromeda polifolia*, *Vaccinium microcarpum*, *V. vitis-idaea*, *V. uliginosum*, *Empetrum nigrum* ssp. *hermaphroditum*), *Rubus chamaemorus* and *Sphagnum* spp.

CHRONOLOGY OF LITHO- AND BIO-STRATIGRAPHICAL CHANGES IN THE INVESTIGATED MIRES

A comparison of the age of 1) lithostratigraphic units and their limits, 2) marked "recurrence surfaces" and 3) transition to ombrogenic peat according to bio- (and chemo-) stratigraphical indications is presented in Fig. 10. Here the time of mire initiation is considered a climatically induced lithostratigraphic limit and included in the survey. Having in mind the several dating problems and the statistical overlapping of dates, there seemingly is a concentration of litho- and bio-stratigraphic events to certain limited periods (Fig. 10 and Table 5).

Nilssen and Vorren (1991) compiled the lithostratigraphical events in peat deposits, from several sites in a larger region of Norway, and they included four of the sites of the present study. The main difference between the lithostratigraphical horizons distinguished in the present paper (Table 5) and those of Nilssen and Vorren (1991) is that the number of marked stratigraphical events are fewer in the present investigation, and that the proposed mean ages differ slightly (Nilssen & Vor-

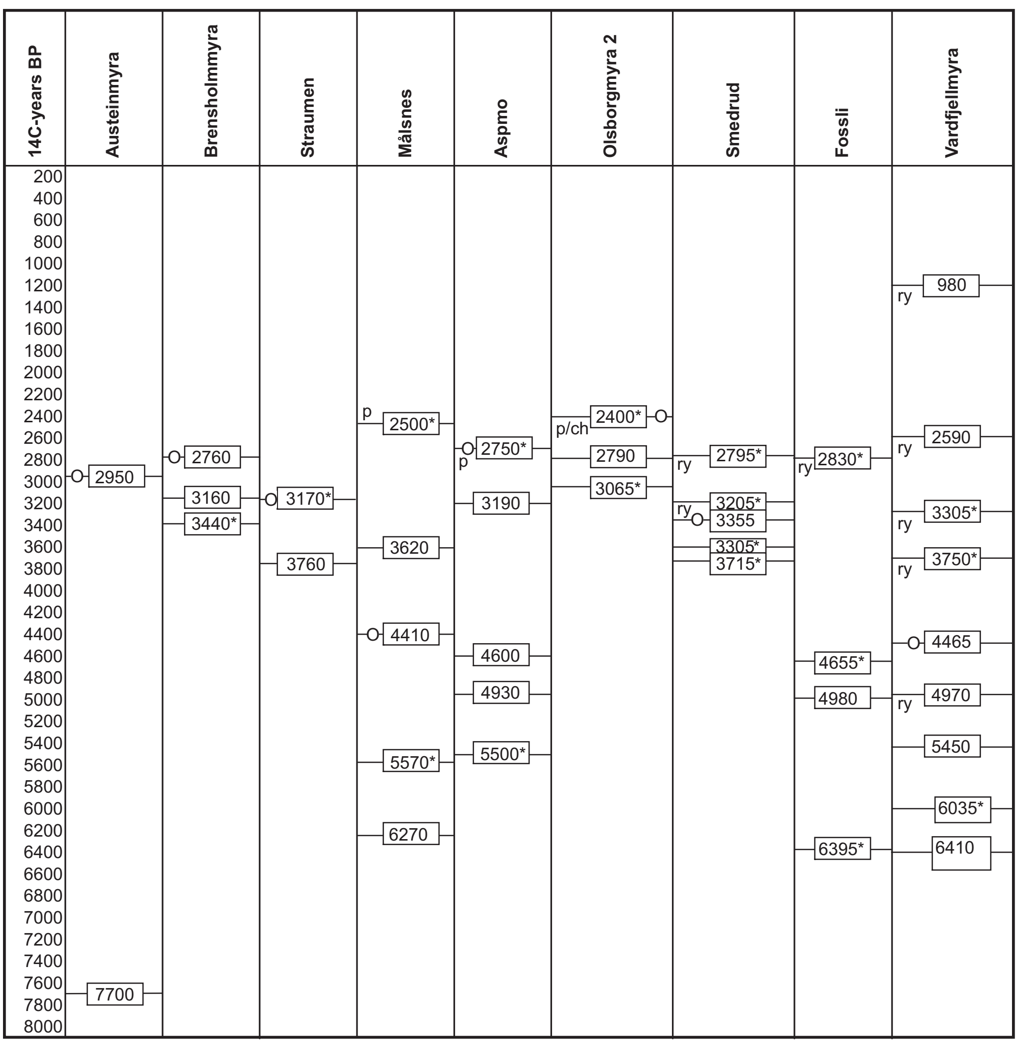

Fig. 10. Chronological and geographical survey of the most important stratigraphical changes in the studied bogs and fen: 1) Lithostratigraphical changes of major peat types and sudden shifts of humification from dark to light (= ry). 2) Pollen-analytically (p) and chemically (ch) indicated transitions from minerotrophic to ombrotrophic (0) environments at the bog surface. Asteriscs indicate extra- or interpolated dates

Table 5. Suggested mean age of climatically induced litho- and biostratigraphical changes in the investigated *Calluna-Racomitrium* bogs. Ages refer to probable clusters in Fig. 10

Radiocarbon years BP	Calibrated years BP	Calibrated years AD/BC	Youngest and oldest direct or interpolated date BP	Number of sites with lithological changes
2750	2855	905 BC	2500–2950	8 (out of 9)
3160	3380	1430 BC	3065–3200	5 (out of 9)
3330	3550	1600 BC	3305–3355	5 (out of 7)
3708	4060	2115 BC	3620–3760	4 (out of 7)
4530	5275	3325 BC	4410–4655	4 (out of 5)
4960	5680	3730 BC	4930–4980	3 (out of 5)
5515	6295	4345 BC	5470–5570	3 (out of 5)
6360	7300	5450 BC	6270–6410	3 (out of 4)

ren 1991: bracketed): 2750 (2850), 3160 (3125), 3330 (3425), 3710 (3800), 4530 (4525) BP.

The time interval for the transition from geogenic to ombrogenic peat in the region studied spans from 4465 to 2400 BP. However, most transitions occur in the interval 3355 to 2760 BP (5 out of 8). The age of the geogenic-ombrogenic transition seems to be most related to the individual development of each bog, or to the initial age of the local peat formation.

A feature, which seems to be general to almost all bogs (except Austeinmyra, site No. 1), is the decrease of peat growth rates after the transition to ombrotrophic environments (Fig. 11).

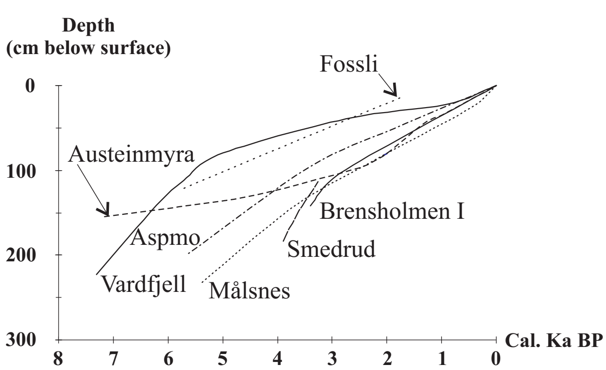

Fig. 11. Peat accumulation pattern of the investigated mires

The lithostratigraphical horizons concentrating about 2750 BP (2950–2590) (Table 5) are especially important in the oligotrophication process, and obviously connected with changes towards more humid climate conditions. The investigation of Kilian et al. (1995) has demonstrated the existence of an unexplained ^{14}C-reservoir effect in bogs, which amounts to 100–250 radiocarbon years. The authors also indicate that a pronounced climatic wetting about 2812–2734 cal. years BP led to the formation of the well-known “Grenz-horizont” of the European Atlantic bogs. This climatic event, also documented by van Geel et al. (1996), is reflected in calibrated single dates spanning over a time interval between 3358 and 2810 cal. years BP. Many dates of the bogs studied here fall within this interval (Fig. 12).

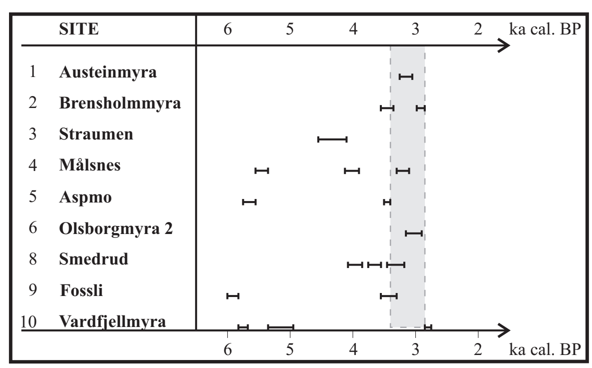

Fig. 12. Calibrated ages of the lithostratigraphical changes in the investigated bogs and fen. The interval 3358–2810 cal. years BP is shaded

However, this interval may contain two distinctly separated stratigraphic changes, such as in the case of Brensholm-myra (No. 2) and Smedrud (No. 8). Better dating may be achieved by means of wiggle-matching of several dates in a single profile (cf. van Geel et al. 1996).

When subtracting a mean reservoir age of 175 years for the theoretical 2750 BP horizon of Table 5, the “real age” (2575 BP) would imply a range of possible dates from about 2670 to 2370 cal. years BP because of a ^{14}C-plateau (Stuiver & Becker 1993). A reservoir effect may explain the relatively old date of the main lithological change in the Austeinmyra peat. On the other hand, the change dated at Vardfjellmyr, a small sub-alpine bog, may indicate no or little reservoir effect in this individual bog, if other sources of error are excluded (such as contamination by rootlets). The individual bogs can react to a climatic change with a time lag according to Kilian et al. (1995). This may also explain that different dates may refer to one and the same climatic incident.

Van Geel et al. (1996) refer to several sources that support the theory of an abrupt climatic change between 2800 and 2710 cal. years BP. This event is known for long since in the Alps, where salt and copper mines were regionally destroyed by water catastrophes about 2800 cal. years BP (Nordhagen 1933). The $\Delta^{14}C$ peaks of the dendrochronological series are reflected as wet intervals in the peat stratigraphy when wigglematched. The mentioned abrupt climatic change between 2800 and 2710 cal. years BP correlates with a marked $\Delta^{14}C$ peak. The reason for the correlation between $\Delta^{14}C$-peaks and climatic deterioration seems to be periods of decreasing solar activity (Van Geel et al. 1999). Decreasing solar activity means a decrease in the protecting shield of solar electromagnetic and corpuscular emission. This, in turn, causes an increase in cosmic ray activity in the outer atmosphere where radiocarbon is formed. Increased cosmic ray fluxes change the density of the ozone layer, develop a denser cloudcover and form an aerosol layer in the stratosphere and an atmospheric veil. Decreased solar activity also causes a decrease in the UV-radiation to the Earth, which carries a great part of the solar energy to the atmosphere.

CONCLUSIONS

A "normal" development of the *Calluna-Racomitrium* bogs investigated includes three major stages: 1) a basal carr- or swamp forest peat. 2) an intermediate Cyperaceae peat. 3) an upper Ericales-*Sphagnum* peat.

In the regional mire section II (the *Calluna-Racomitrium* bog section; Fig. 1) a pollen- and spore assemblage of *Calluna*, Ericales *p.p.*, *Rubus chamaemorus* and *Sphagnum* characterizes the ombrotrophic bog expanse vegetation. There may be a delay (time lag) between the lithological change that induces a change from minerotrophic to ombrotrophic environments and the termination of a mineral ground water influence on vegetation.

Transition from geogenic to ombrogenic peat spans from 4465 to 2400 BP, with a concentration in the interval 3355–2760 BP. The transition time seems related to the initial age of the peat formation at each site.

Lithostratigraphical changes, which are presumed to be climatically induced, occur about 2780, 3160, 3355, 3710, 4530, 4960, 5515 and 6360 BP. However, absolute dates are so limited, and calibrated dates so scattered, that these mean figures are just preliminary. Profound climatic changes to cooler and wetter conditions about 2750 BP, however, seem to be fairly well established.

Combined litho- and biostratigraphical changes occur most frequently between 2950 and 2590 BP. Most of these dates may represent a radiocarbon plateau between 2710–2370 cal. years BP, if a radiocarbon reservoir effect in bog peat is assumed. If no or a negligible reservoir effect is assumed, the dates concentrate about 2855 cal. years BP. It should, however, again be emphasized that the present material is too limited and the dates too scattered, to give a decisive support to any of these alternatives.

Peat growth rates decreased after the minerotrophic/ombrotrophic transition.

ACKNOWLEDGEMENTS

Cand. scient Christin Jensen, IB, University of Tromsø is gratefully acknowledged for preparation of the samples and the diagrams, Ms. Hilkka Falkseth and Ms. Tove Midtun, IB, University of Tromsø for drawings, and Prof. Tore Vorren and Dr. Geoff. Corner, IG, University of Tromsø for information on raised beaches. I also want to express my gratitude to the National Laboratory of Radiological Datings, NTNU, Trondheim. The investigations have been financed by the annual budgets of the University of Tromsø.

REFERENCES

AABY B. 1986. Palaeoecological studies of mires: 145–164. In: Berglund B.E. (ed.) Handbook of palaeoecology and palaeohydrology. J. Wiley & Sons, Chichester.

ALM T., VORREN K.-D. & MØRKVED B. 1996. Holocene tree-line fluctuations and climate in Central Troms, northern Norway. Historical Biology, 12: 25–38.

ARNELL S. 1956. Illustrated moss flora of Fennoscandia. I. Hepaticae. CWK Gleerup, Lund.

AUNE B. 1993. Temperaturnormaler. Normalperiode 1961–90. Det norske meteorologiske institutt. Klima. Rapport 02/93: 1–63. (in Norwegian).

BARBER K.E. 1981. Peat stratigraphy and climate change. A. Balkema, Rotterdam.

BENUM P. 1958. The flora of Troms fylke. Tromsø Museums Skrifter 6: 1–402 (with 546 maps). (in Norwegian).

BRUUN I., 1967. Climatological summaries for Norway. Standard normals 1931–60 of the air temperature in Norway. Det norske meteorologiske institutt. Oslo.

ELVEN R. & VORREN K.-D. 1980. Flora and phytogeography of the Habafjell-Skrubben area of Central Troms. Tromura. Naturvitenskap, 9: 1–64.

ENGELSKJØN T. & SKIFTE O. 1995. The vascular plants of Troms, North Norway. Revised distribution maps and altitude limits after Benum: The flora of Troms fylke. Tromura. Naturvitenskap, 80: 1–227.

EUROLA S. & VORREN K.-D. 1980. Mire zones and sections in North Fennoscandia. Aquilo Ser. Bot., 17: 39–56.

FÆGRI K. & IVERSEN J. 1989. Textbook of pollen analysis. 4. ed., J. Wiley & Sons, Chichester.

FØRLAND E.J. 1993. Nedbørnormaler. Normalperiode 1961–90. (Precipitation normals in Norway 1961–90). Det norske meteorologiske institutt. Klima. Rapport, 39: 1–63. (in Norwegian).

FREMSTAD E. & ØVSTEDAL D.O. 1978. The phytosociology and ecology of grey alder (*Alnus incana*) forests in central Troms, north Norway. Astarte, 11: 93–112.

FRISVOLL A.A., ELVEBAKK A., FLATBERG K.L. & ØKLAND R.H. 1995. Sjekkliste over norske moser (Checklist of Norwegian mosses). NINA Temahefte 4: 1–104. (in Norwegian).

GRANLUND E. 1932. De svenska högmossarnas geologi. Sveriges geologiska undersökningar. Ser. C, 373: 1–193. (in Swedish).

GRIMM E. 1992. *Tilia* version 1.10. Illinois State Museum. U.S.A.

HALLINGBÄCK T. & HOLMÅSEN I. 1985. Mossor. En fälthandbok. (Mosses. A field handbook). Stockholm. (in Swedish).

KILIAN M.R., van der PLICHT J. & van GEEL B. 1995. Dating raised bogs: New aspects of AMS wiggle matching, a reservoir effect and climatic change. Quatern. Sci. Rev., 14: 959–966.

KOTILAINEN M. 1933. Zur Frage der Verbreitung des atlantischen Florenelements Fennoskandias. Ann. Bot. Fenn., 4(1): 1–75.

KROG H., ØSTHAGEN H. & TØNSBERG T. 1994. Lavflora. Norske busk- og bladlav. (Lichen flora. Norwegian macro-lichens). University Press, Oslo. (in Norwegian).

LID J. & LID D. T. 1994. Norsk flora. (The Norwegian flora of vascular plants). Det norske samlaget, Oslo. (in Norwegian).

LUNDQVIST G. 1967. Geological radiocarbon datings from the Stockholm station. Sveriges Geologiska Undersökningar, Ser. C, 589: 1–101.

MÖRNSJÖ T. 1968. Stratigraphical and chemical studies on two peatlands in Scania, South Sweden. Bot. Notiser, 121: 343–360.

NILSSEN E. & VORREN K.-D. 1991. Peat humification and climate history. Norsk Geologisk Tidsskrift, 71: 215–217.

NORDHAGEN R. 1933. De senkvartære klimavekslinger i Nordeuropa og deres betydning for kulturforskningen. Institutt for sammenlignende kulturforskning. Serie A, 12: 1–246. (in Norwegian).

NYHOLM E. 1993. Illustrated flora of Nordic mosses. Fasc. 3: 141–244. Nordic Bryological Society, Lund.

POST von L. & GRANLUND E. 1926. Södra Sveriges torvtillgånger. Sveriges Geologiska Undersökningar, Ser. C, 335: 1–127. (in Norwegian).

RUUHIJÄRVI R. 1963. Zur Entwicklungsgeschichte der nordfinnischen Hochmoore. Ann. Bot. Fenn., 34(2): 1–40.

SIGMOND E.M.O., GUSTAVSON M. & ROBERTS D. 1984. Bedrock map of Norway. M. 1:1 million. Norwegian Geological Survey.

SJÖRS, H. 1950. Regional studies in North Swedish mire vegetation. Bot. Notiser, 2: 173–222.

SOLLID J.L. & TORP O. 1984. Quaternary map of Norway. M. 1:1 million. Norwegian Geological Survey.

SPJELKAVIK S. 1986. Skogstyper i indre Troms. (Forest types in central Troms). Cand. real. thesis in Plant ecology, Institute of biology and geology, University of Tromsø. (in Norwegian).

STOCKMARR J. 1971. Tablets with spores used in absolute pollen analysis. Pollen et Spores, 13: 615–621.

STUIVER B. & BECKER M. 1993. High-precision decadal calibration of the radiocarbon time scale AD 1950–6000 BC. Radiocarbon, 35(1): 35–65.

Van GEEL B., BUURMAN J. & WATERBOLK H.T. 1996. Archaeological and palaeoecological indications of an abrupt climate change in The Netherlands, and evidence for climatological tele-connections around 2650 BP. Journal of Quaternary Science, 11(6): 451–460.

Van GEEL B., RASPOPOV O.M., RENSSEN H., van der PLICHT J., DERGACHEV V.A. & MEIJER H.A.J. 1999. The role of solar forcing upon climate change. Quaternary Science Reviews, 18: 331–338.

VORREN K.-D. 1972. Stratigraphical investigations of a palsa bog in northern Norway. Astarte, 5: 39–71.

VORREN K.-D. 1979a. Vegetational investigations of a palsa bog in northern Norway. Tromura Naturvitenskap, 5: 1–176.

VORREN K.-D. 1979b. Die Moorvegetation in Namdalen. Tromura Naturvitenskap, 8: 1–102.

VORREN K.-D. 1993. Pollen-nedfall og vegetasjon. En undersøkelse i et skogsområde i Målselv, Nord-Norge, 69^{o} N.br. (Pollen deposition and vegetation. A study in a forested area of Målselv, northern Norway). Polarflokken, 17(2): 285–319.

VORREN K.-D. & ALM T. 1985. An attempt at synthesizing the Holocene biostratigraphy of a “type area” in northern Norway by means of recommended methods for zonation and comparison of biostratigraphical data. Ecologia Mediterranea, 11(1): 53–64.

VORREN K.-D., JENSEN C., MOOK R., MØRKVED B. & THUN T. 1993. Holocene timberlines and climate in North Norway – an interdisciplinary approach. Paläoklimaforschung, 9: 115–126.

VORREN K.-D., ALM T. & MØRKVED B. 1996. Holocene pine (*Pinus sylvestris* L.) and grey alder (*Alnus incana* Moench.) immigration and oscillations in central Troms, northern Norway, and their palaeoclimatic implications. Paläoklimaforschung, 20: 271–292.

VORREN K.-D., EUROLA S. & TVERAABAK L.U. 1999. The lowland terrestrial mire vegetation about 69^o N lat. in northern Norway. Tromura Naturvitenskap, 84: 1–90.

VORREN K.-D. & JOHANSEN B. 1990. Synopsis and numerical analysis of the pre-alpine, sub-alpine and low-alpine mire vegetation of the Uleberg-Skrubben area, North Norway. Aquilo Ser. Bot., 28: 79–92.

VORREN K.-D. & STAVSETH A. 1996. Late Holocene vegetation and climate changes interpreted from pollen influx and plant macrofossils from sediments of an alpine lake in North Norway. Paläoklimaforschung, 20: 257–270.

VORREN K.-D. & VORREN B. 1976. The problem of dating a palsa. Two attempts involving pollen diagrams, determination of moss subfossils and C^{14}-datings. Astarte, 8: 73–81.