The early Holocene climate and sea-level changes in Lofoten and Vesterålen, North Norway

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A submarine peat at Petvik in western Lofoten has been pollen-analysed and ^{14}C-dated. The Petvik data, and some additional data from Ramså in northern Vesterålen, indicate that the sea level at the 7–8 m Main shoreline isobase sank below present mean sea level around 9900 B.P. and at least below −2.85 m during the time of maximal regression (9000–8000 B.P.). The 'Tapes' transgression passed the present mean sea level at c. 7600 B.P. (interpolated). The climate during the early Holocene sea level regression was at least as warm as present in the whole area, although birch woodlands became established c. 800 years later in western Lofoten than in northern Vesterålen.

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The submarine peats at Petvik on the southern side of Vestvågøy in Lofoten (Figs. 1, 2 and 3) have long been recognized. Mr. K. Ringstad, Leknes, reported the occurrence of the peat to the University of Bergen, and Moe (1975) made a preliminary investigation. He found that the submarine peats were part of a more or less continuous deposit between c. 5 m above and 2 m below present mean tide level. Above the present shore the peat is covered by littoral sand and gravel, deposited during the 'Tapes' transgression(s).

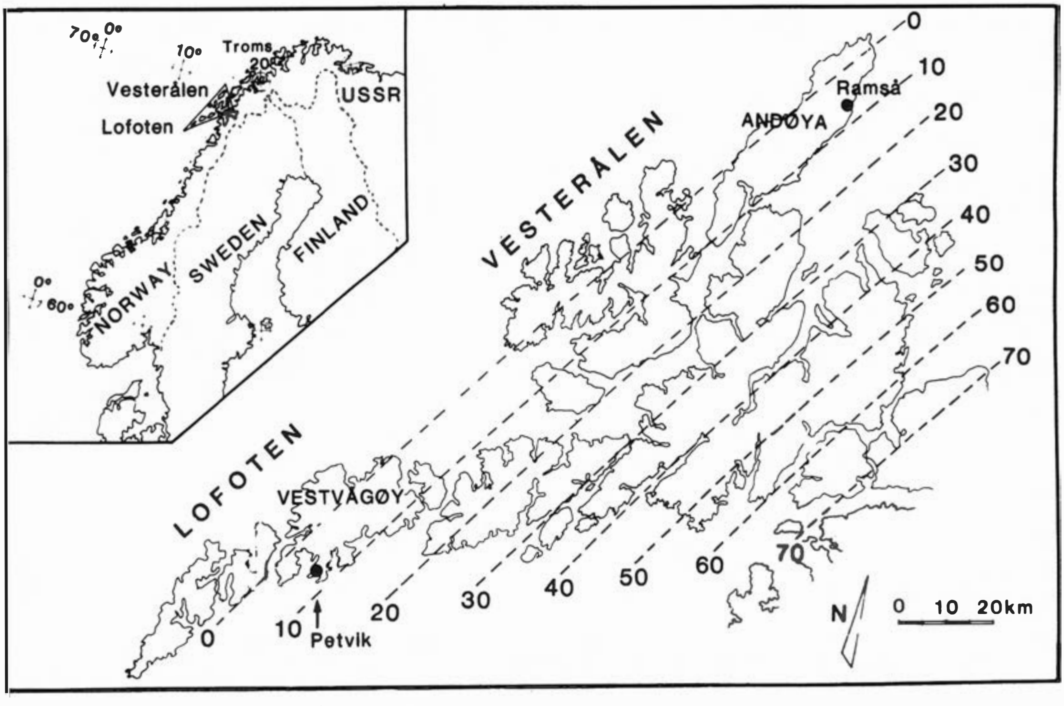


Fig. 1. Map of the Lofoten and Vesterålen areas with isobases of the Main shore line from approximately 10,900–10,300 B.P. The Petvik and Ramså sites are both situated just outside the 10 m isobase. (After Møller 1984).

Fig. 2. View of Petvik towards the south and south-west.

We have investigated a 0.7 m long core from the thickest part of the submarine peat. Nine samples from the core were analysed for pollen according to the principles quoted in Fægri & Iversen (1975) (KOH + acetolysis). Two ^{14}C-samples were sieved, and in order to reduce the contamination effect from younger roots only the insoluble remnants < 1 mm were submitted for dating. The sediments above the mean low water neap level were levelled and cored June 20, 1984. The botanical nomenclature follows Lid (1974).

Site description – Petvik

Fig. 4. shows two levelled transects below mean tide level at Petvik. The uppermost peat is 1.8 m below the recent upper growth limit of *Ascophyllum nodosum*. No coring was carried out below the mean low water neap level. Aerial photographs suggest that peat also occurs below this level, in an area where the sea floor is about 2 m below mean tide level, according to Map 74 (Norges Sjøkartverk, Stavanger 1984).

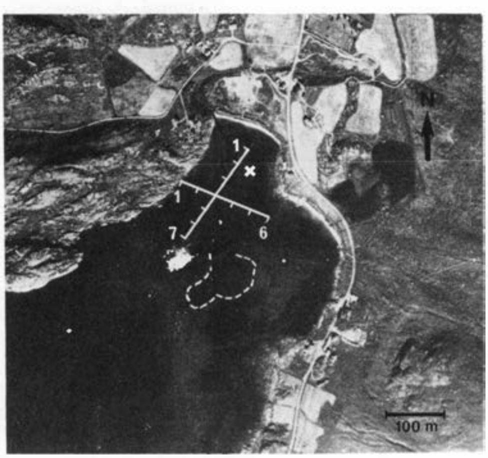


Fig. 3. Aerial photograph of the Petvik bay and its surroundings. Two transects, approximately in a northeast-southwest and southeast-northwest direction have been cored and levelled (the crossing lines). Coring points indicated by short right-angled hooks. The transects are shown in Fig. 4. The presumed sub-low-water peat occurrence is within the broken line. The sub-littoral slope break may be recognized c. 50 m to the south-west of the broken line. Coring site for the pollen-analytical profile is marked with a cross.

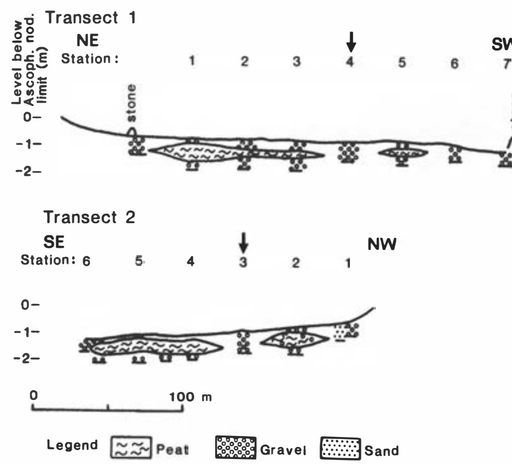


Fig. 4. The transects of Fig. 3 which have been cored and levelled. Crossing points of the transects are marked by vertical arrows. The peat has been formed autochthonously within a series of (shore mire) elements. The largest element is situated between the island and the eastern shore. The pollen profile has been sampled from that peat occurrence.

Lithology and biostratigraphy of the submarine peat

Lithologically there are two distinctly different layers in the investigated Petvik peat section (Fig. 5):

1) an upper muddy and sandy/gravelly deposit, interpreted as a mixture of inwashed allochthonous sand/gravel and peat, and 2) a very compact *Carex-Phragmites*-herb peat. Within the latter, three different sublayers may be distinguished: a)

a lower, highly decomposed *Phragmites – Carex* peat, b) an intermediate medium decomposed herb-Cyperaceae-birch peat, containing a birch log, and c) an upper highly decomposed *Phragmites – Carex* peat. The substratum is weathered bed-rock.

Biostratigraphically there are five different intervals in the compact peat from the top downwards:

1) The lowermost spectrum contains much Chenopodiaceae and *Plantago maritima,* both indicating close proximity to sea shore vegetation. Mountain plants like *Oxyria,* and high values of Ericales, mainly *Empetrum,* indicate periglacial environments. *Hippuris* indicated the start of peat formation in shallow stream pools.
2) The two-three spectra above are dominated by grass pollen, obviously derived mainly from *Phragmites,* which is abundantly present in the lithological section as macroremains. *Galium,* Onagraceae, *Caltha, Montia,* and *Potentilla*-type indicate an oxygen-infiltrated mesotrophic mire. Nitrophilous taxa like *Vicia cracca, Eu-Rumex, Matricaria*-type, and *Ranunculus* indicate proximity to nitrogen-rich, stable seaweed drift lines.
3) The three next spectra contain much birch, *Filipendula* and Apiaceae pollen, indicating a mire above the influence of marine waters.
4) The third and also the second spectrum from the top of the core contain *Caltha,* Onagraceae, *Galium* (Rubiaceae), and *Potentilla*-type, all indicators of an oxygen-infiltrated mesotrophic mire.
5) The two uppermost spectra contain much Chenopodiaceae and *Plantago maritima,* indicating proximity to the sea shore.

Shore level definitions

The terms 'mean tide level' and 'mean sea level' refer to the NNN level (North Norwegian zero) of the Geographical Survey of Norway (NGO) (Fig. 6). This is considered to be approximately 6–8 cm above the Z_0 level of Norges Sjøkartverk (1985) in the Lofoten-Vesterålen area (Skøthaug, NGO, pers. comm.). The Z_0 level, which will be the reference level of this study and denoted m.t.l. (= mean tide level), is the 'mean water' above the zero level of the Norwegian bathymetric maps. The latter zero level corresponds to the 'low water of the vernal equinox' (Norges Sjøkartverk 1985), which again probably corresponds very closely to the mean low water of spring tides (Fig. 6). The NNN level is considered to be c. 0.3 m below the upper *Fucus vesiculosus* growth limit, on an average (Corner 1980). Roughly, therefore, the Z_0 level is c. 0.35 m below this limit, which has often been used as a basis line for altitudinal measurements. The *Fucus vesiculosus* limit as well as other biological limits may, however, vary in their height relation to mean tide level according to local ecology (e.g. E. Oug and T. E. Lein, Univ. of Bergen, pers. comm.).

In the present study the *Ascophyllum nodosum* upper growth limit has been used as the basis for levellings, and the reservations mentioned above also concern this limit.

In sheltered positions *Ascophyllum nodosum* tends to replace *Fucus vesiculosus* (Lewis 1976, 117–119), as in Petvik. Baardseth (1970) considers the upper *Ascophyllum nodosum* growth limit to be slightly above 'mid-tide level'.

At Bodø, c. 80 km SE of Petvik, the m.t.l. is 1.55 m above the zero level of Norges Sjøkartverk, i.e. the mean low spring tide level. The vertical distance to the mean high of spring tide should be symmetric from m.t.l.: 1.55 m, and the range of spring tides therefore 3.1 m. The range of the mean neap tides at Bodø is 1.65 m (Miljøstatistikk 1978), (Fig. 6).

At Kabelvåg, c. 35 km NE of Petvik, the mean spring tide range is 3.34 m (Norges Sjøkartverk 1985).

The minimal vertical extent of the regression at Petvik

In a zone about mean high spring tide level, the so-called sea shore mires may form in sheltered positions (Fig. 6) (Fjelland et al. 1983).

These mires, and other mesotrophic oxygen-infiltrated mires, may be recognized by certain taxa, e.g. Cyperaceae, *Potentilla*-type, *Galium* (Rubiaceae), and in the present case *Phragmites,* which is recognized by its macroremains, might be added. True sea shore mires are inundated normally once or twice a year by the highest spring tides, but are hardly reached by the monthly highest tides. Their vertical extent is normally 0.2–0.3 m, and the mean high spring

PETVIK, Vestvågøy, N.Norway, 1 m below Ascophyllum nodosum – limit

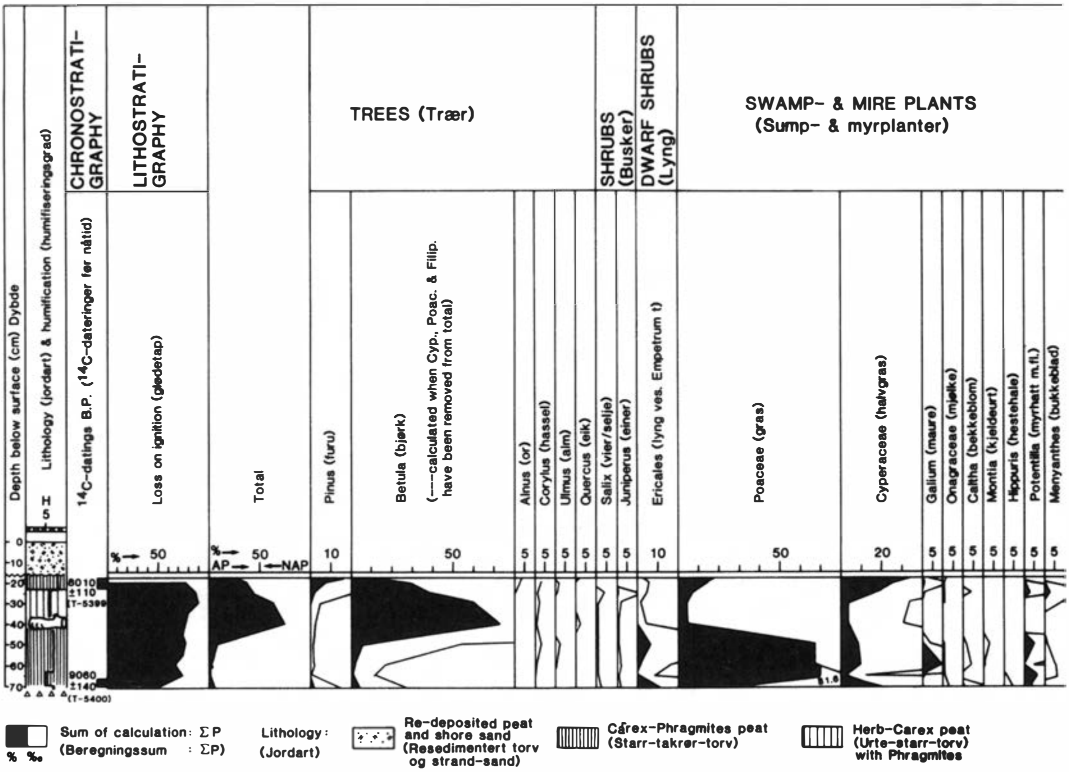


Fig. 5. Pollen- and spore diagram from Petvik.

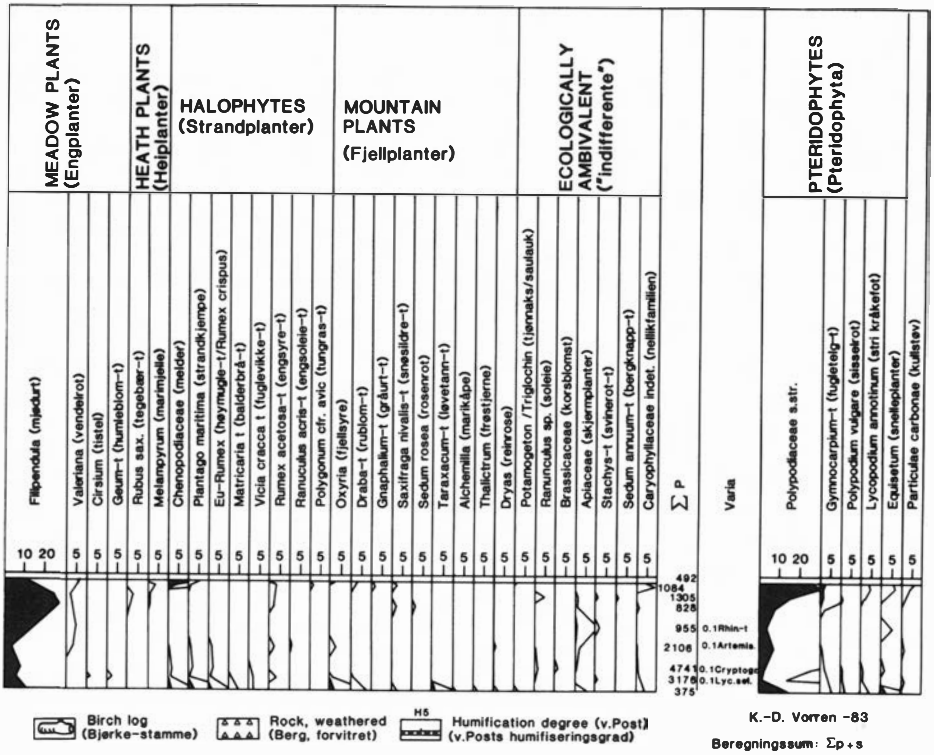
tides will indicate the horizontal centre line of sea-shore mire biotopes (R. Elven, Univ. of Tromsø, pers. comm.). It implies that these mires may be formed around 1.55 m above the m.t.l. at Bodø. At Petvik the figure is probably more like that at Kabelvåg. With caution it can be set at 1.6 ± 0.15 m.

The surface of the sampling site was levelled to 1.0 m below the *Ascophyllum* limit, which is placed c. 0.35 m above the m.t.l. Thus the surface of the coring site is 0.65 m below m.t.l.

The periods of sea shore proximity, reflected in the biostratigraphy 0.7 m and 0.15 m below the sediment surface, were dated to 9060 and 8010 B.P., respectively. These levels are 1.35 m and 0.8 m below m.t.l. The peat deposited between the two shore periods of the regression-transgressing cycle contains two different layers which *may* be sea shore mire peat: a lower one at 1.35–1.10 m and an upper one between 0.9 and 0.8 m below present m.t.l. The intermediate herb-Cyperaceae-birch peat was probably deposited during the regression maximum, which may be interpolated at 8700–8400 B.P. and was definitely above sea water influence.

The highest possible position of m.t.l. during the time of the two assumed sea shore mire periods would be: 1) 1.35 m (distance from present m.t.l. to lowermost peat) + 1.45 m (distance from present m.t.l. to lowest possible level of mire formation) = −2.8 m, c. 9000 B.P., 2) 0.8 m (distance from present m.t.l. to uppermost peat) + 1.45 m = −2.25 m, c. 8000 B.P.

During the regression maximum the lowermost position of m.t.l. must have been more than 1.1 m (distance from present m.t.l. to lowermost part of the herb-Cyperaceae-birch peat layer) + 1.75 m (distance from m.t.l. to the uppermost sea shore mire limit) = 2.85 m below present m.t.l. The lowermost peat occurrence levelled in the Petvik bay is 1.8 m below the *Ascophyllum* limit (Fig. 4), i.e. 1.45 m below m.t.l. Probably there are still lower occurrences. Peat is formed metachronously along the slope gradient during the



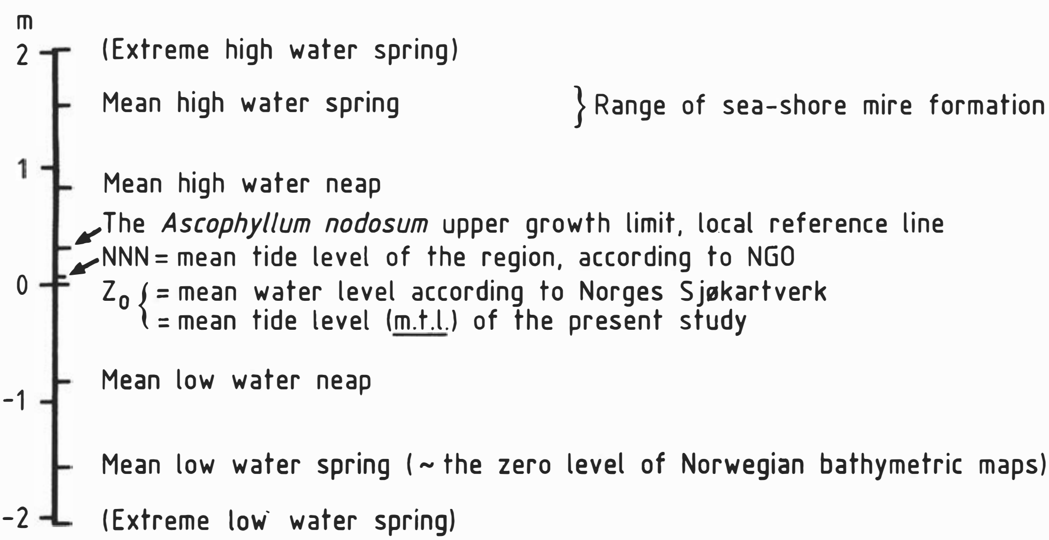


Fig. 6. Different sea shore levels mentioned in the text. The oscillation ranges are illustrated by data from Bodø, 85 km SE of Petvik. Data have been extracted from different sources. The range of sea-shore mire formation has been indicated.

regression periods. Møller (1984) dated the top and base of a peat deposit at Petvik. The basal layer, which was 2 m below mean tide level, was dated at 8350 ± 60 B.P. This implies m.t.l. position c. 3.5 m (or more) below the present m.t.l. at the actual time.

Comparison with the Ramså profile, Andøya

The Main shore line, which was formed during the Younger Dryas (Andersen 1968), occurs approximately 7–8 m a.s.l., both at Petvik and Ramså on Andøya (Fig. 1) (Møller 1984). The two sites may therefore be expected to have rather similar early Holocene shore-line displacement. Marthinussen (1962) constructed a shore line displacement curve for Ramså which has been modified by Møller (1984). Marthinussen based his displacement curve on ^{14}C-datings of peat mainly from a section near the mouth of the Ramså stream (Fig. 7). This peat is overlain by the 'Tapes' beach ridge, which consists of several metres of sand and gravel. An attempt at reconstructing the stratigraphy described by Marthinussen is presented in Fig. 8.

Fig. 7. A section of the subsoil peat exposed at the bank of the lower part of the river Ramså, Andøy. The lowermost part of the peat is at river level. It is presumed that Marthinussen (1962) obtained his samples for ^{14}C-dating from this site. The 'Tapes' littoral beach ridge covers the peat.

Holmboe (1903) investigated plant macro-subfossils from a section near the outlet of the Ramså stream. The results are summarized in Fig. 8.

Common to both sections is a layer of mixed organogenic and minerogenic compounds near the base of the profile, which was ^{14}C-dated to c. 10,600 B.P. (Marthinussen 1962). Holmboe (1903) maintains that all three organogenic layers found by him below the 'Tapes' beach ridge were fresh-water deposits (limnic-telmatic). However, the finding of a *Ruppia maritima*-fruit in layer 2 reveals the influence of marine waters. Noteworthy is the fact that no *Betula* seeds, but some *Empetrum* seeds occur in this layer. The deposits thus seem to be older than c. 9500 B.P., the date of birch woodland establishment on Northern Andøy (Alm, in prep.). The *Betula*-rise was preceded by an *Empetrum* phase in the vegetational development, the onset of which has been dated at about 10,470 ± 130 B.P. (T-5890 A) (Alm, in prep.).

Pollen-analysis of two samples from the basal organo-/minerogenic deposits sampled by J. Møller near the Ramså outlet shows: 1) Lowermost sample: dominance of grasses, presence of *Oxyria* and *Dryas,* and the only lignoses present are *Salix* spp. 2) Uppermost sample, 15 cm above the former: dominance of Cyperaceae and presence of *Oxyria, Cryas, Salix* and *Empetrum.* Long distance transport of a few *Betula* and *Pinus* pollengrains. Both spectra are of a Younger Dryas type (Vorren 1978).

According to Holmboe (1903), layer 2 of the section studied by him consisted of 'fine, layered marine sand' with rounded shore-pebbles. As it may be connected with the '*Empetrum*-period' of Younger Dryas/Preboreal transition (10,470–9500 B.P. Alm, in prep.) according to the seed-analyses, it may correlate with same layers between the datings 10,600 and 9900 B.P. of Marthinussen's section (Fig. 8). An interpolated age of the *Ruppia*-layer at about 10,200 B.P. would place the sea level at Ramså c. 1 m above the present one at the beginning of the Holocene.

The dating of the uppermost thick peat of Marthinussen's section (7400 ± 150 B.P.) indicated

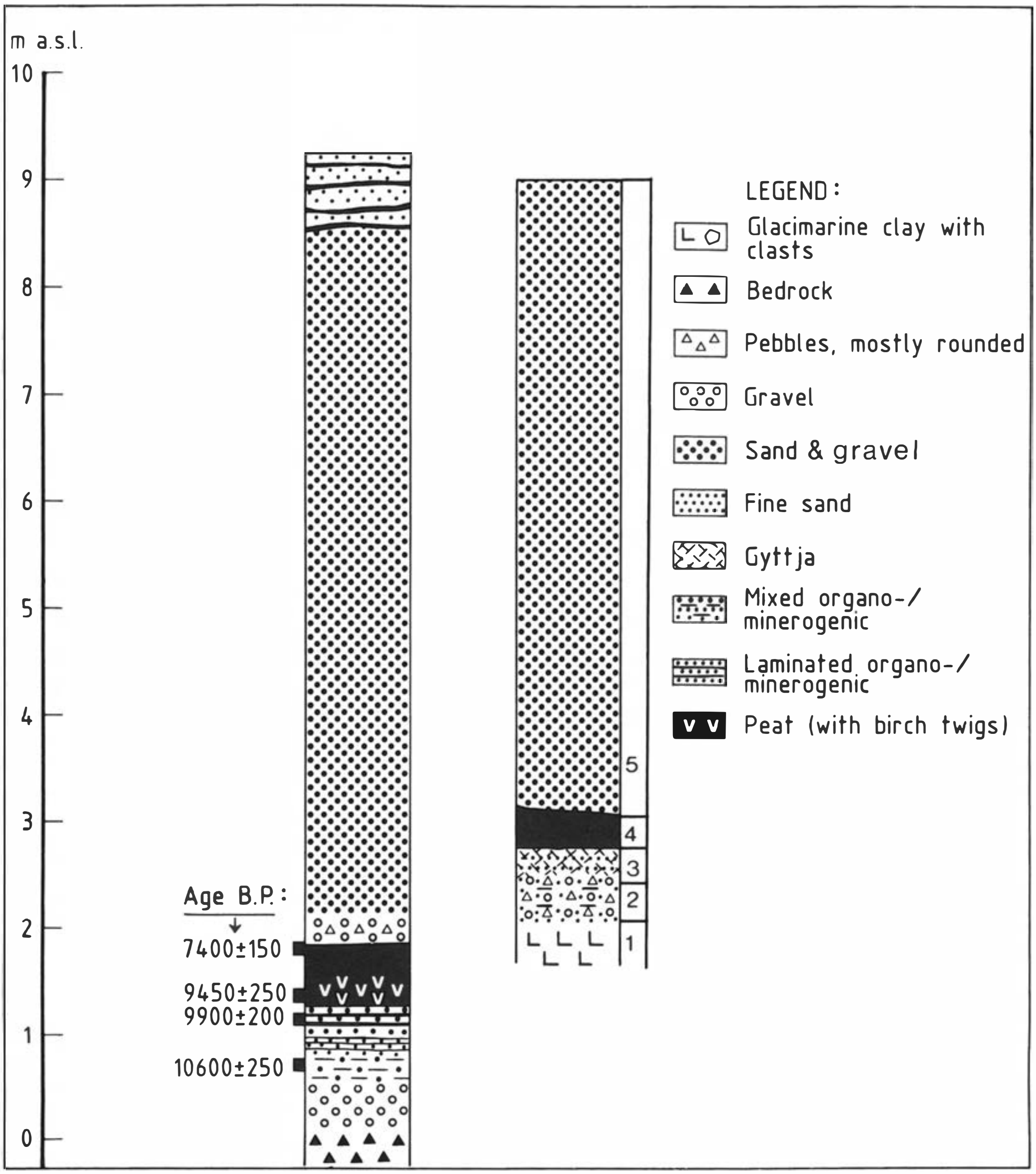


Fig. 8. Two sections of the 'Tapes' littoral beach ridge at Ramså at different levels, showing similar stratigraphy in the lowermost interval, which is supposed to be littoral, autochthonous and of Younger Dryas and early Preboreal origin. Left column: deduced from Marthinussen (1962). Right column: deduced from Holmboe (1903).

the moment when sea level rose above + 1.75 m at the 7–8 m Mainshoreline-isobase in the district of Vesterålen – Lofoten.

The data from Petvik and Ramså form the basis for the construction of a shoreline displacement curve during the Holocene at the mentioned isobase of the Vesterålen – Lofoten district (Fig. 9).

The early Holocene climate in North Norway

The climate of the Boreal Chronozone, 9–8000 B.P. (Mangerud et al. 1974), has been considered warm and dry in South Norway, according to Blytt & Sernander's theory of climate changes

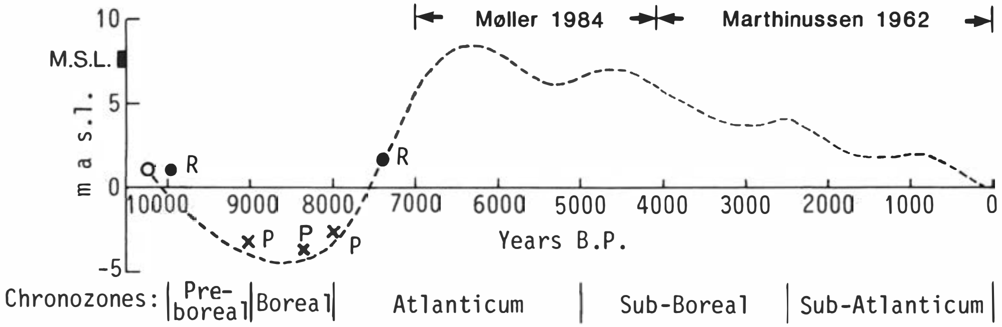


Fig. 9. A Preboreal-Boreal shore line displacement curve at the 7–8 m Main shore line in the Lofoten and Vesterålen archipelago, based on data from Petvik (xP) and Ramså (oR). MSL = Main shore line.

(Holmsen 1922, p. 12). More recent investigations show that maximum altitudinal tree limits in South Norway were achieved during Boreal times (Moe et al. 1978, Moe 1979). At Petvik there seems to be a rather late invasion of birch-trees. Morphological distinction of the *Betula* pollen shows that spectra below the sample 50 cm below surface (i.e. older than c. 8700 B.P.) in the Petvik diagram (Fig. 5) contain mainly *Betula nana*-type (subspherical, thin-walled, and with low aspides). In the sample 50 cm below surface, 72 % of the *Betula* pollen was classified as tree pollen (probably mostly *Betula pubescens* Ehrh.s.l.) and 28% as *Betula nana*-type. Above this sample, macrofossils show that *Betula pubescens* grew on the spot.

Around Stormyra, c. 1 km north of Petvik, *Betula* trees were present 9800 B.P., but disappeared or receded shortly after (Moe 1982). *Betula* trees became reestablished somewhat before 8550 ± 100 B.P. The decline of *Betula* during the early Preboreal is probably correlated with climatic deteriorations, which are evidenced by glacial re-advances during the Preboreal. These events have been dated by Andersen (1968) and Corner (1980).

The *Betula* increase in the Petvik profile is considered to be synchronous with the re-establishment found in Stormmyra.

The earliest indications of birch woods in North Norway may be dated to c. 10,000 B.P. (Fimreite 1980, Hyvärinen 1985, Moe 1982). Several datings show that birch woodland in coastal districts formed mainly during the upper Preboreal (Hyvärinen 1975, Prentice 1981, 1982, Eronen & Hyvärinen 1984, Vorren & Alm 1985).

In North Norway and adjacent areas, pollen diagrams show that the Preboreal and Boreal birch woodlands were rich in ferns and lycopods. This feature has been interpreted as an indication of cool, maritime conditions, especially in the present continental areas (Aario 1943, Sorsa 1965). However, in central Troms, fern-dominated woodland occurred also in the warm Atlantic period.

Possibly such woodlands mainly express the soil conditions during this climate, and thus represent a successional stage in the 'mesocratic' woodland formation (Walter & Straka 1970).

Prentice (1981) found a high presence of *Diphasium* spores in her sediments from the Boreal chronozone on the Varanger peninsula, and seems to favour *Diphasium (Lycopodium) complanatum* as the source, indicating a continental type of the fern- and lycopod-dominated birch woods.

This hypothesis gains support from the contemporary occurrence of *Phragmites* macro-remains. *Phragmites* occurs scattered along the north Norwegian coast to Andøy, but reaches more to the north in continental areas. In North Norway, the species is common in the south part of the Middle Boreal vegetational zone (Eurola & Vorren 1980) and southwards, i.e. 200–250 km south of Petvik. The species seems to have had a rather large distribution, especially during the Boreal. It is recorded as an abundant macrofossil in that chronozone in two lakes on Vanna, c. 70°15′ N (Vorren 1985).

Those indications of a rather warm and perhaps also dry climate during the Boreal, or at least the early part of it, are contradicted by the absence and late reestablishment of birch at Petvik. This problem remains unsolved until more palaeo-botanical evidence has been acquired.

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