Late Weichselian and early Holocene vegetation, climate, and floral migration at Utsira, North-Rogaland, southwestern Norway

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A Late-glacial/early Holocene pollen diagram from Utsira is interpreted as showing six main climatic periods: (1) The pleniglacial period from deglaciation (probably before 14,000 BP) to ca. 13,000 BP with an Artemisia pioneer vegetation on disturbed mineral soil. (2) The Bølling (BØ) amelioration (ca. 13,000 to ca. 12,300 BP) with a Salix shrub dominance on humus soils. (3) The 'Older Dryas' (OD) deterioration (ca. 12,300 to ca. 12,000 BP) with a recurrence of herb dominance. (4) The Allerød (AL) amelioration (ca. 12,000 to ca. 11,000 BP) with the re-establishment of Salix shrubs. Two minor climatic deteriorations are traced at about 11,750 and 11,300 BP. (5) The Younger Dryas (YD) Stadial (ca. 11,000 to ca. 10,000 BP) with a dominance of Sedum and other mineral-soil herbs. (6) The early Holocene with locally established woodlands of birch, hazel and Populus. July means of 7–10°C in the pleniglacial, 12–14°C in the first half of YD, 12–14°C in the last half, and at least 14–16°C in the early Holocene are indicated. Strong winds may have prevailed throughout the Late-glacial, inhibiting woodland development. In periods of climatic deterioration, colder winters and increased wind activity are suggested as the main factors deleterious to humus-soil vegetation. Boreal-circumpolar, arctic-alpine, and eurasatic plants dominated the Late-glacial flora.

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This paper is the fourth contribution from a project aimed at reconstructing the Late-glacial vegetational and climatic history in SW Norway (see Paus 1988, 1989a, b). The sites included (Fig. 1) lie west of the Younger Dryas moraine and above the marine limit, thereby containing complete Late-glacial sequences back to pre-Bølling deglaciation. One sedimentary sequence from each site has been pollen analysed in detail, with high pollen sums and closely spaced samples. In addition, Betula pollen size statistics from selected levels have been carried out.

The remote westerly position of Utsira means that it was deglaciated early. Therefore a palynological investigation here should reveal a record of the earliest Late-glacial pioneer vegetation in SW Norway. In addition, Utsira is at the western end of an east–west transect (Fig. 1), and it was chosen to test the hypothesis that there was a climatic gradient influencing Late-glacial vegetational development similar to the climatic gradient which exists today.

Site description

Øvre Kvilhaugmyra bog (4°52'E, 59°19'N, 35 m a.s.l.) lies in the northwestern part of the island of Utsira, which is situated ca. 20 km off the coast west of Karmøy island (Fig. 1). The sizes of the catchment and the bog surface are ca. 30,000 m² and 4,400 m², respectively.

With the exception of small areas of planted conifer woods and sheltered single specimens of Sorbus aucuparia and Populus tremula, Utsira is treeless today. The local vegetation in the Øvre Kvilhaugmyra area is characterized by dry grasslands, heavily influenced by grazing (Nordhagen 1923; Stokka 1971). Dominant species are Festuca vivipara, Nardus stricta, Holcus lanatus, Juncus squarrosum, and Potentilla erecta. Eriophorum angustifolium, Juncus conglomeratus, Hydrocotyle vulgaris, and Sphagnum cuspidatum dominate the bog vegetation. Øvre Kvilhaugmyra bog shows distinct signs of peat-cutting and is today partly covered by water.
The mean temperatures of the warmest and coldest months are 13.5°C (August) and 2.0°C (February), respectively (Bruun 1967). Annual precipitation is 1000 mm (Bruun & Håland 1970). In contrast, in coastal areas of the Rogaland mainland the mean temperature of the warmest month is 1–2° higher than at Utsira; the coldest month is 1–2° lower, and annual precipitation is between 1100 and 1500 mm. At Utsira, the annual mean wind velocity is 8.2 ms⁻¹ (Stokka 1971), which is far stronger than elsewhere in Rogaland. At the exposed Skudenes on Karmøy, for example, the mean velocity is 3.8 ms⁻¹ (Andresen 1979).

The Utsira bedrock is of Caledonian age, mainly gabbro and diorites, except for the granites and granodiorites in the southwestern part (Simmond et al. 1984). There are diverging opinions about the marine limit (ML) at Utsira. Undås (1948) postulates a beach ridge 30 m a.s.l. and ca. 150 m north of Øvre Kvihauagmyra as representing ML. Sørensen et al. (1987) seem to indicate ML at about 0 m a.s.l., whereas Anundsen (pers. comm., cf. Anundsen 1985, Fig. 8) suggests ML at about 10 m a.s.l.

The only glacial striations found on Utsira are positioned north–south. They may have been made by a Skagerak glacier (Undås 1948; Ringen 1964), a northerly trending flank of a Ryfylke/Boknfjord glacier (Andersen et al. 1987), or a coastal ice dome over central W. Norway (Anundsen 1990). The three hypotheses all imply that Utsira was deglaciated earlier than the mainland, i.e. before 14,000 BP (Anundsen 1985; Paus 1989a).

Methods
Field work. Material for pollen analysis was obtained using a 110 mm diameter Livingstone corer (see Table 1 for sediment description). The coring point was chosen after lithostratigraphical exploration using a 54 mm diameter “Russian” sampler. Well-developed Late-glacial sediments were found only in a limited area of a few square metres. Here, the coring equipment was unable to sample below 270 cm, whereas steel rods penetrated the minerogenic deposits down to bedrock at 330 cm.

Laboratory work and analytical methods. Pollen analysis and methods follow Paus (1988).
Table 1. Sediment lithology for the core from Utsira studied pollen analytically. The description is based on Troels-Smith's (1955) system.

<table>
<thead>
<tr>
<th>DEPTH cm</th>
<th>TYPE</th>
<th>COLOUR</th>
<th>CONSTITUENTS</th>
<th>PHYSICAL CHARACTERISTICS</th>
</tr>
</thead>
<tbody>
<tr>
<td>130-158.5</td>
<td>DY</td>
<td>DARK BROWN</td>
<td>Dg2, Ld2, Dh+, Ag+</td>
<td>nig.3+ sicc.1 strat.1 elas.2</td>
</tr>
<tr>
<td>158.5-161</td>
<td>GYTTJA</td>
<td>BROWN</td>
<td>Dg1, Ld3, Th+, Dh+, Ag+</td>
<td>nig.3 sicc.1 strat.1 elas.2</td>
</tr>
<tr>
<td>161-161.5</td>
<td>CLAY-GYTTJA</td>
<td>YELLOW-BROWN</td>
<td>Ld0.2, As2, Ag+</td>
<td>nig.2 sicc.1 strat.0 elas.2</td>
</tr>
<tr>
<td>161.5-168.5</td>
<td>CLAY/SILT</td>
<td>LIGHT GREY</td>
<td>As2, Ag1, Ga1 Ld3+, Th+</td>
<td>nig.1-2 sicc.2 strat.0 elas.1</td>
</tr>
<tr>
<td>168.5-179</td>
<td>CLAY-GYTTJA</td>
<td>BROWN</td>
<td>Ld2, As2, Dg+, Th+</td>
<td>nig.2 sicc.2 strat.1 elas.2</td>
</tr>
<tr>
<td>179-193</td>
<td>CLAY/SILT-GYTTJA</td>
<td>BROWN</td>
<td>Ld1,As1,Ag1, Dg+, Th+</td>
<td>nig.2 sicc.2 strat.0 elas.1</td>
</tr>
<tr>
<td>193-200</td>
<td>SILT-GYTTJA</td>
<td>BROWN</td>
<td>Ld2,As1,Ag1, Dg+</td>
<td>nig.2 sicc.2 strat.0 elas.1</td>
</tr>
<tr>
<td>200-204</td>
<td>CLAY/SILT-GYTTJA</td>
<td>BROWN</td>
<td>Ld0.2,As1,Ag1, Dg+</td>
<td>nig.2 sicc.2 strat.0 elas.1</td>
</tr>
<tr>
<td>204-216</td>
<td>SILT-GYTTJA</td>
<td>BROWN</td>
<td>Ld0.1,As1,Ag2, Dg+</td>
<td>nig.1 sicc.2 strat.0 elas.1</td>
</tr>
<tr>
<td>216-270</td>
<td>CLAY/SILT</td>
<td>BLUE-GREY</td>
<td>As2,Ag2, Ld3+,Ga+</td>
<td>nig.2-2 sicc.2 strat.0 elas.0</td>
</tr>
</tbody>
</table>

Betula pollen size statistics were carried out using Paus's (1988) approach. Tephra grains were identified by polarizing microscopy (Persson 1966).

The pollen diagrams. Pollen data were processed and the percentage and absolute diagrams (Figs. 3, 4, 5) drawn by the program CORESYSTEM (Michelsen 1985). The percentage calculation basis, $\Sigma P$, comprises the terrestrial (including assumed secondary) and unidentified pollen. For a constituent $X$ within the categories of spores, aquatic pollen, and pre-Quaternary microfossils, the calculation basis is $\Sigma P + X$. The pollen diagrams contain 59 spectra analysed at 1-4 cm intervals. $\Sigma P$ per spectrum ranges from 163 to 2418 (mean 1331) comprising 22-47 taxa (mean 34). The diagrams include 109 terrestrial pollen taxa and 27 aquatic pollen and spore types. Pollen and spore types are grouped following Paus (1988), except for presumed reworked tree pollen, which also appears as primary in the Holocene (e.g. Pinus, Corylus). This pollen is grouped among the primary pollen of trees and shrubs. Nomenclature follows Lid (1985). Zonation of diagrams includes local pollen assemblage zones (paz), chronozones (Mangerud et al. 1974; Welten 1982), and the zonation of Firbas (1949).

Table 2. Results and characteristics of the Utsira $^{14}$C samples. Datings were carried out by the Laboratory of Radiological Dating in Trondheim, Norway.

<table>
<thead>
<tr>
<th>DATING LEVEL</th>
<th>DEPTH cm</th>
<th>MATERIAL</th>
<th>LOSS ON IGNITION(%)</th>
<th>SECONDARY POLLEN(%)</th>
<th>LAB. REF.</th>
<th>$^{14}$C-YEARS B.P.</th>
<th>$\delta^{13}$C</th>
<th>PRONOUNCED DATING ERRORS</th>
<th>ASSUMED AGE B.P.</th>
<th>DATING FEATURE</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>158.75-160</td>
<td>GYTTJA</td>
<td>25-45</td>
<td>-</td>
<td>T-6346A</td>
<td>7,020±130</td>
<td>-27.5</td>
<td>QUAT.ROOTS</td>
<td>&lt;9,500</td>
<td>LATE CORYLUS RISE</td>
</tr>
<tr>
<td>2</td>
<td>167.25-169.75</td>
<td>CLAY-GYTTJA</td>
<td>10-15</td>
<td>0.1</td>
<td>T-6345A</td>
<td>10,040±200</td>
<td>-24.9</td>
<td>QUAT.ROOTS</td>
<td>10,500</td>
<td>SEDIMENT SHIFT</td>
</tr>
<tr>
<td>1</td>
<td>212.5-217</td>
<td>MINEROG. GYTTJA</td>
<td>5-8</td>
<td>7.4</td>
<td>T-6344A</td>
<td>12,990±250</td>
<td>-20.9</td>
<td>QUAT.ROOTS, REM.MATERIAL</td>
<td>13,000</td>
<td>BOLLING AMELIORATION</td>
</tr>
</tbody>
</table>
Radiocarbon dates

The NaOH-soluble (A) fractions of three gyttja samples (thickness 1.25-4.5 cm) have been dated conventionally. With one exception, the NaOH-insoluble (B) fractions were also dated. Results are given in Table 2 and Fig. 2.

A seemingly too young result of T-6346A and divergent results of the A and B fractions in the other two levels indicate that dating errors are present. Downward-penetrating roots from a well-developed aquatic flora throughout the low-organic Utsira sequence may have been critical, especially for the results of the NaOH-insoluble (B) fractions (Kaland et al. 1984). The lowermost sample may also be influenced by redeposition (see below). The local bedrock is poor in lime and the basin catchment is small, so any hardwater effect would be negligible.

Similar or even more serious problems were encountered for the other gyttja samples included in the SW Norway project (Paus 1988, 1989a, b). These unreliable datings highlight the importance of AMS dating terrestrial macrofossils (Ammann & Lotter 1989). Material from Utsira has been submitted for AMS dating and will be published together with the macrofossil analyses now being carried out by Hilary H. Birks and the coleopteran analyses of Geoffrey Lemdahl.

Until then, any chronology at Utsira must to a greater extent than at the other project sites (Paus 1988, 1989a, b) be based on correlation of distinct stratigraphical events. These include the mid-interstadial Empetrum rise (ca. 12,000 BP, see Paus 1988, 1989a, b), the AL/YD transition (ca. 11,000 BP), and the regional Corylus rise in the early Holocene (ca. 9,500 BP, Huntley & Birks 1983, Paus 1988). In general, of the fractions of minerogenic samples, the soluble one has proved to give the most reliable result (Kaland et al. 1984; Paus 1988, 1989a; Blystad & Seising 1989). T-6344A dating the early transition between minerogenic and more organic sediments (ca. 13,000 BP) may thus be reliable. Furthermore, the YD ash layer (ca. 10,600 BP, Mangerud et al. 1984) is used as a marker horizon. This tentative chronology results in the sediment accumulation rates shown in Fig. 2.

Late Weichselian and early Holocene vegetation history

Introduction

Some limitations and interpretative problems prevent a straightforward reconstruction of past vegetation at Utsira. First, reworked pollen (e.g. pre-Quaternary microfossils, Carya, Nyssa, Liquidambar) in basal sediments has been found (cf. Iversen 1936; Paus 1988, 1989a, b). Second, as the diameter of Betula pollen is easily influenced by abiotic factors (Kristiansen et al. 1988; Paus 1989a), D/P ratio statistics and pollen morphology studies are here regarded as being more reliable in differentiating Betula nana from tree birches.

Third, because the Utsira chronology is based on correlation of levels, it must be stressed that the influx estimates are tentative and probably deviate somewhat from the actual ones. This is crucial in the discussion of whether tree birches were present or not at Utsira during the Late-glacial. If my estimates are reliable, Late-glacial birch influx reaches a maximum in mid-Allerød (paz U4a) of about 290 grains cm⁻²a⁻¹ (Fig. 4) including some Betula nana (Fig. 6). Similar influx
values are interpreted to reflect the lower limit for sparse local tree birch representation (Hyvärinen 1976; Pennington 1981). Though pollen deposition depends on sedimentary environments and may vary somewhat between sites (see e.g. Pennington 1973; Davis & Brubaker 1973; Davis et al. 1984), here it is concluded that birch forests never developed on Utsira in the Late-glacial. In the mid-Allerød, however, local representation of isolated tree birches/copses cannot be excluded.

Fourth, the following factors suggest that the Utsira diagram may contain high proportions of long-distance pollen: (1) The lack of any local, high pollen-producing forests at Utsira; (2) a low regional pollen representation, as Utsira is small and surrounded by ocean; (3) the strong wind activity at Utsira. Furthermore, these factors should indicate that the long-distance problem is accentuated on Utsira compared with other Rogaland sites. However, after the Oldest Dryas, with well-represented reworked pollen, the Late-glacial pine pollen in SW Norway is almost certainly long-distance dispersed from S. Scandinavia or the continent (Berglund 1966; Huntley & Birks 1983), but both its relative and absolute values throughout the Late-glacial are higher elsewhere in Rogaland (Austad & Erichsen 1987; Paus 1988, 1989a, b) than on Utsira. This fact emphasizes that the long-distance effect should not be underestimated in Late-glacial studies even on mainland Norway. In the Late-glacial, western and eastern/southeastern winds prevailed in Scandinavia (Rapp 1982; COHMAP 1988). The latter, created by high pressures over the Scandinavian ice cap, may have changed direction as the ice extent changed. Thus, SW Norway may have been susceptible to long-distance pollen from many directions. In SW Norway, likely long-distance taxa are e.g. Xanthium-type (western/southern origin?), Ephedra and Picea (eastern/southeastern origin?), and Alnus (A. viride?), Quercus, Ulmus, and Polycnemum/Paronychia type (southern origin?). At Utsira, most of the tree birch pollen was probably brought from mainland Norway. The high number of pollen grains counted in each spectrum increases the chance of recording long-distance taxa, possibly also including plants that produce low amounts of pollen. Therefore, firm conclusions about local conditions based on single grain occurrences of e.g. Typha, Echium, Solanum, should be avoided.

Fifth, the problem of 'no-analogues' between present and Late-glacial vegetation (Iversen 1954; Birks 1981) and the inherent pollen-analytical limitations (Fægri & Iversen 1975, 1989) permit only a coarse reconstruction of Late-glacial plant communities. In the following discussion of vegetation history, I will refer to the simplified classification of Late-glacial communities used by Paus (1988, 1989a). For a complete list of taxa included in each community, see Paus (1988). In brief, assuming that birch woodlands were absent from the Utsira Late-glacial, these communities are:

1a: Dry, open-ground communities.
1b: Dry grasslands.
2a: Wet, open-ground communities, including extreme snow-beds.
2b: Moist grasslands, including early-melting snow-beds.
3: Juniper-dwarf-shrub heaths.
4: Tall-herb grasslands.
5: Willow shrubs/copses.
6c: Open birch vegetation.

Vegetation development

Before ca. 12,750 BP: Artemisia–Pinus local pollen-assemblage zone (U1). – The clayey/silty sediment contains high proportions of assumed reworked pollen (e.g. Carya, Liquidambar, Nyssa, Pterocarya) that probably originated from eroded glacial deposits within the catchment or by winds carrying eroded material from the North Sea continent (Paus 1988, 1989a, b). This sediment mixed with small stones continues below the lowermost pollen-analysed level (228 cm) down to 270 cm. Probing using steel rods indicated bedrock at 330 cm depth. Sedimentation was most probably initiated before 14,000 BP, which is the minimum age for deglaciation of the N. Rogaland mainland (Anundsen 1985; Paus 1989a).

Where estimated, the influx is less than 250 grains cm$^{-2}$a$^{-1}$, which is comparable to influx in newly deglaciated areas elsewhere in Rogaland (Paus 1988, 1989a, b) and modern tundra (Ritchie & Lichti-Federovich 1967; Fredskild 1973). Low influx, the presence of mineral-soil taxa (e.g. Artemisia, Chenopodiaceae, Brassicaceae, Helianthemum, Cerastium-type), and high percentages of reworked pollen suggest discontinuous vegetation on immature soils, heavily influenced by soil erosion/cryoturbation. Unstable communities such as 1a in exposed areas and 2a in
Fig. 3. Pollen percentage diagram of terrestrial taxa from Øvre Kvilhaugmyra, Utsira. The scale of exaggeration is $\times 10$. $^{14}$C dates of the dating levels are shown in Table 2 and Fig. 2. Lithology symbols follow Troels-Smith (1955).
Fig. 3 (continued).

| LOCAL PAZ | POLYCEAE | RUMEX SECT. ACETOBA | APIACEAE | CALTHA TYPE | RUMEX SECT. LONGIFOLIUS | SEDUM | POTENTILLA TYPE | URTICA | ONAGRAE | FILIPENDULA | PLANTAGO MARITIMA | PLANEAGUS LANCEOLATA | LOTUS TYPE | POLYCHEROMYPHAEACEA TYPE | SPIEGLIARIA | SCROPHULARIA | PARRHASIA PALUSTRIS | GENTIANA NIVALIS TYPE | SCROPHULARIACEAE | PRUNUS PLATANANA | ARCTIUM TYPE | KOENIGIA ISLANDICA | ASPERULA | PLANTAGO MAJOR | DIBERONI | SEA PEACHIGA HIRICUS TYPE | ROSEA | GENTIANA POLYGANDRATHE TYPE | SANGUINARIA OFFICINALIS | GENTIANA SEPIUMTYPE | ANTHRACE TYPE | LACTUCA Cternia TYPE | RHINANTHUS TYPE | RUBUS | ELYMUS AERARIUS | CHINUS | SALIPPA STELLARIS TYPE | FRENCHCIA VULGARIS | FRENCHCIA TYPE | VULGARIS | FABACEAE | GALEA | APUS | PLANTAGO CORONOPUS | GENISTA TYPE | CARYOPHYLLACEAE | ECHIUM | ORUS OCTOPETALA | STYRAX | CENTAUREA MONTANA TYPE | LUPINUM TYPE | LUPUS ODOUR VULGARIS | PARACISSACRIS TYPE | CALIFERULA | HELICANTHUS | SUCISIA | PRAESTRACELA | FICUS | PAPYRACERATTA | PAPPYRACERATTA | CARPINES | OF ENGELEROPHA | ILEX | LIQUIPIRANBAR | GNYST | NESTA | SOCARA | CASTANEA | ACRE | UNIDENTIFIED | POLLEN SUM 10^3 |

| SECONDARY | POLLEN SUM 10^3 |

| QUATERNARY POLLEN | QUATERNARY PILELE SPORES | VERNULATE LATE KSIS | DEPTH BELOW SURFACE (cm) |
sheltered areas were present, probably as parts of a mosaic. Biostratigraphically, U1 is divided into two subzones.

U1a (Chenopodiaceae–Thalictrum subzone, before ca. 13,000 BP) is characterized by low loss-on-ignition (2–5%), high values of *Pinus* and other secondary pollen (30–60% ΣP), and well represented *Artemisia* and other taxa included in the open-ground communities 1a (e.g. Chenopodiaceae, Brassicaceae) and 2a (e.g. *Thalictrum, Huperzia selago*). Although U1a lacks diagnostic taxa such as *Papaver radicatum*-type
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Fig. 5. Percentage and absolute diagrams of spores and aquatic pollen from Øvre Kvilhaugmyra, Utsira. The scheme is similar to Figs. 3 and 4.

(however, found as seeds below U1; Hilary Birks, pers. comm.) and Dryas octopetala, it is ecologically comparable to the Oldest Dryas zones described from other sites in Rogaland (Paus 1988, 1989a, b).

Ulb (Salix–Achillea-type–Poaceae transitional subzone, ca. 13,000 to ca. 12,750 BP) shows an increased organic content in the sediments (loss-on-ignition 5–17%), decreasing Artemisia, Helianthemum, and reworked pollen, and rises in or appearance of Salix, Cyperaceae, Poaceae, Cerastium-type, Achillea-type, and Rumex spp. This may indicate a reduction of dry open-ground communities and a tendency towards stabilized soil and denser vegetation cover in which dry grasslands (1b; e.g. Achillea-type, Aster sect. Cichorium, Poaceae) and moist grasslands (2b; e.g. Rumex sect. acetosa, Poaceae) expanded. In wet open-ground communities (2a), Cerastium-type (pollen) and Salix herbacea (macrofossils,
Hilary Birks, pers. comm.) were better represented. Together with low influx values, this all suggests that the U1b vegetation was still at a pioneer stage.

The U1 aquatic macrophyte flora is poor in species (Fig. 5), but is characterized by an abundance of *Ranunculus* sect. *Batrachium*. Its seeds have been found throughout the silt/clay layer down to 270 cm depth (Hilary Birks, pers. comm.). *Sparganium*-type, usually appearing as the only pioneer water-plant taxon in the Rogaland Late-glacial (Paus 1988, 1989a, b), is also present.

**Ca. 12,750 to ca. 12,300 BP: Salix local pollen-assemblage zone (U2).** At the U1/U2 transition, *Artemisia, Achillea*-type, and Poaceae percentages decrease, secondary and unidentified pollen reach minimum values, and *Salix, Empetrum, Filipendula, Apiaceae, Lychnis/Dianthus*-type, *Polygonum bistorta*-type, *Plantago maritima* and several other taxa appear or increase. The total pollen influx rises from 300 grains cm$^{-2}$a$^{-1}$ to about 2,000 grains cm$^{-2}$a$^{-1}$ (Fig. 4). The latter is comparable to high-productive forest tundra (Ritchie & Lichti-Federovich 1967) or birch woodland (Hyvärinen 1976). This all reflects developing vegetation cover and a change towards stable humus soils. Communities such as dwarf-shrub heaths (community 3) with *Betula nana* (Fig. 6) and *Empetrum* and tall-herb grasslands (4 with *Filipendula, Apiaceae, Lychnis/Dianthus*-type) developed. The *Salix* expansion, reaching 600 grains cm$^{-2}$a$^{-1}$ in late U2 (Fig. 4), most likely reflects the local establishment of willow shrubs/copses (5) (see discussion in Paus (1988). However, the occurrence of *Koenigia islandica*, *Montia, Saxifraga* spp., *Cerastium*, and *Salix*
herbacea leaves (Hilary Birks, pers. comm.) show the persistence of wet open-ground communities. Dry open-ground communities are reflected by Artemisia, Helianthemum, Armeria, and Plantago maritima; grasslands (1b: Plantago major, Sanguisorba officinalis, Rumex longifolius-type, 2b: Rumex sect. acetosa, Parnassia, Polygonum bistorta-type, Botrychium) were widespread. Thus, a diverse vegetation characterised U2.

The next step in the aquatic succession includes a rise in Sparganium-type and the appearance of Myriophyllum-and Potamogeton-species (Fig. 5). Of these, M. spicatum and P. sect. Colegeton indicate eutrophic conditions (Lid 1985). Moreover, Ranunculus sect. Batrachium is still frequent, and Typha latifolia occurs once (long-distance dispersed?).

U2 probably represents the middle of the Bølling Chronozone. The U2 willow-shrub communities may be an analogous successional stage to the mid-Bølling tree birch communities on the Rogaland mainland (Paus 1988, 1989a, b). If reliably dated, the Bølling Empetrum rises at Utsira and Liastemmen (Paus 1989a) are synchronous (12,750-12,700 BP).

Ca. 12,300 to ca. 12,000 BP: Rumex-Poaceae local pollen-assemblage zone (U3). - The lithology is silt/clay gyttja with slightly decreasing loss-on-ignition (10-13%). Biostratigraphically, U3 shows distinct minima in Salix, Betula, Empetrum, Filipendula, Apiaceae, Caltha-type, and total pollen influx (300-800 grains cm$^{-2}$a$^{-1}$, comparable to tundra or low-producing forest tundra; Ritchie & Lichti-Federovich 1967; Hyvärinen 1976), maxima in Rumex sect. acetosa and Poaceae, and a concentration of reworked taxa (e.g. Corylus, Picea, Platycarya, Liquidambar). This all suggests increased soil erosion, vegetation break-up, and degradation of humus soil communities (3, 4, 5). However, within community 3 Betula nana values are maintained (Fig. 6). In broad outline, U3 shows a regression towards a vegetation very similar to that of U1b and is characterized by moist grasslands (2b: Poaceae, Rumex sect. acetosa, Parnassia, Botrychium), wet open-ground communities (2a: Montia, Saxifraga spp., Cerastium-type), and drier herb communities (1a, b; Poaceae, Helianthemum, Artemisia, Plantago maritima, Lotus-type).

Recurring U1b conditions may also be observed in the aquatic flora by higher values of Ranunculus sect. Batrachium and decreasing Sparganium-type. The maximum in the eutrophic Myriophyllum spicatum strengthens the suggestion of increased soil erosion and inwash of nutrients into the lake.

The U3 events probably parallel the zone Ic of Iversen (1954) and are correlated with the ‘Older Dryas’ changes in N. Rogaland (Paus 1988, 1989a). Here, the local tree-birch vegetation regressed, which may be detected in U3 by the minimum of tree-birch pollen (Figs. 3, 4, 6). On the other hand, declining local pollen production results in a relative maximum in the long-distance pine pollen from south of Norway (Figs. 3, 4; see Berglund 1966; Huntley & Birks 1983).

Ca. 12,000 to ca. 11,000 BP: Salix-Empetrum local pollen-assemblage zone (U4). – Early U4 is characterized by rising loss-on-ignition (13-16%), increasing Salix, Betula, Empetrum, Rumex sect. longifolius, Filipendula and Sparganium-type, and a drop in Rumex sect. acetosa, Ranunculus sect. Batrachium, and Myriophyllum spicatum. Total pollen influx increases and varies between 1,000 and 2,400 grains cm$^{-2}$a$^{-1}$, comparable to high productive forest tundra or birch woodland (Ritchie & Lichti-Federovich 1967; Hyvärinen 1976).

U4 reflects progressive development of vegetation and soil. Humus soil communities such as 3 (Empetrum, Juniperus), 4 (Filipendula, Urtica), and 5 (Salix) expanded. Grasslands that may have included Poaceae, Plantago maritima, Rumex sect. longifolius (1b) and Rumex sect. acetosa, Polygonum bistorta-type, Parnassia, Botrychium (2b) were widespread, and traces of open-ground communities (1a: Artemisia, Helianthemum, Armeria, Plantago maritima, 2a: Koenigia, Cerastium-type, Saxifraga spp., Montia) are found throughout the zone. Changes in representation of the U4 communities permit a division into two subzones.

In U4a (Artemisia-Apiceae subzone, ca. 12,000 to ca. 11,400 BP) the Late-glacial maxima in Salix and total pollen influx (Figs. 3, 4) suggest that the willow shrubs/copseps (5) reached their widest Late-glacial extension. The earliest Utsira records of Populus tremula are from U4a, and scattered tree birches (community 6c) may have appeared locally (see above). Furthermore, Pimpinella-type (1b) and Pinguicula vulgaris (2b) show their first Late-glacial occurrences.

U4b (Sedum subzone, ca. 11,400 to ca. 11,000 BP) reflects a thinning of vegetation by decreasing
Salix and total pollen influx. Sedum expands and reflects an increased importance of herb communities (1, 2 or both; modern reference material of Sedum permitted no differentiation into species or types). The U4b aquatic macrophyte flora shows increases in Sparganium-type, Hippuris, Myriophyllum alterniflorum, and Potamogeton spp. In the last half of U4b, from ca. 11,200 BP, willow-shrubs redevelop (rise in Salix and total pollen influx), Sedum shows a minimum, Echium, Plantago coronopus, and Typha latifolia are recorded by single-grain occurrences (long-distance dispersed?). Two grains of Solanum dulcamara in one level have been found.

U4 correlates with the Allerød sensu Björck & Möller (1987) and Paus (1988, 1989a, b). At Utsira, the willow shrubs/copses appear as the Late-glacial ‘climax’ vegetation, contemporary with the Allerød birch forests on the Rogaland mainland (Chanda 1965; Thomsen 1982; Paus 1988, 1989b).

Ca. 11,000 to ca. 9,800 BP: Rumex-Sedum local pollen-assemblage zone (U5). – Clay gyttja with stable loss-on-ignition (13–17%) in the first half and silty clay with decreasing loss-on-ignition to 3% and high content of exine-damaged (but determinable) pollen in the last half characterize the U5 lithology. Total influx slightly decreases and varies between 900 and 1,500 grains cm$^{-2}$a$^{-1}$, mainly, but it reaches 3,000 grains cm$^{-2}$a$^{-1}$ (comparable to modern birch woodland; Hyvärinen 1976) at the close of U5 (Fig. 4).

Steadily decreasing Salix indicates degradation of the willow-shrub communities (5), whereas a distinct maximum in Salix herbacea leaves (Hilary Birks, pers. comm.) and better represented Koenigia and Saxifraga spp. show expanding wet open-ground communities including snow-beds (2a). The Sedum maximum, at the opening of U5, could thus involve moisture-demanding species such as S. rosea and/or S. villosum. On the other hand, the maximum in Rumex sect. longifolius, probably reflecting taller Rumex spp. (see Paus 1988), indicates expanding herb communities on drier soils (1). Other possible grassland (1b, 2b) taxa are Poaceae, Rumex sect. acetosa, Plantago major, Polygonum bistorta-type, and Selaginella. In dry open-ground communities including Artemisia, Helianthemum, Brassicaceae, and Chenopodiaceae, Dryas octopetala is recorded for the first time in the Utsira Late-glacial. Juniper–dwarf shrub heaths (3) with Betula nana (Fig. 6) and tall-herb communities (4; Filipendula, Urtica) have, for their part, similar representation to that in U4. Empetrum increases, however, in late U5. Among the aquatics, Sparganium-type, Hippuris, Potamogeton sect. Eupotamogeton, and Myriophyllum alterniflorum reach their Late-glacial maxima in U5, possibly resulting from increased soil erosion and outwash of nutrients into the water.

U5 reflects the effects of the Younger Dryas climatic change on vegetation and soil. In levels 170 and 169 cm, small amounts of ash grains (less than 1% of minerogenic particles) are correlated to the Vedde Ash Bed, ca. 10,600 BP (Mangerud et al. 1984). Unlike many other Late-glacial sites from W. Norway (e.g. Braaten & Hermansen 1985; Austad & Erichsen 1987; Kristiansen et al. 1988; Paus 1988, 1989a) the Utsira YD is not marked by a distinct Artemisia maximum. This could indicate that the conditions were more oceanic on Utsira (see Watts 1977; Macpherson 1980). Instead, Sedum appears as the diagnostic YD taxon. Similarly, low Artemisia- and high Sedum-values in the YD are found at Alvøy (Siervik & al. 1985) and Fedje (Danielsen 1986), two other islands at the extreme west of W. Norway. This pattern could also have an edaphic explanation. On the exposed islands, morainic deposits were probably eroded rapidly by wind or sea activity after deglaciation, and thus increasing the importance of bare rock as a substratum. During the YD climatic shift, such a bare-rock dominance in open-ground areas would have favoured most Sedum species but no Artemisia species, according to their present habitat demands (Lid 1985).

Ca. 9,800 to ca. 9,500 BP: Betula–Empetrum–Poaceae local pollen-assemblage zone (U6). – U6 reflects the vegetational effects of the Holocene climatic amelioration, already traced in late U5 by the increases in total pollen influx and Empetrum. High total pollen influx (2,500–3,500 grains cm$^{-2}$a$^{-1}$, comparable to modern birch forests; Hyvärinen 1976), rapid rise in loss-on-ignition (to 25–30%), and increasing Betula, Empetrum, Filipendula, and Poaceae reflect soil development and expanding humus soil communities 3 (with Betula nana; Fig. 6) and 4. Local tree-birch vegetation became established (cf. tree-birch influx of more than 500 grains cm$^{-2}$a$^{-1}$; Figs. 4, 6), mainly composed of Betula pubescens s.s. according to the D/P ratio maximum of about 8 (Birks
1968; van Leeuwaarden 1982). The local appearance of Corylus avellana at the close of U6 is confirmed by the find of one nutshell.

This vegetational closing ends the era of the Late-glacial vegetation and causes the extinction or severe reduction of low-competitive and light-demanding herbs such as Helianthemum, Koenia, Montia, Sedum, Sagina, Polygonum bistorta-type, and Saxifraga spp.

After ca. 9,500 BP: Corylus–Calluna–Plantago maritima local pollen-assemblage zone (U7). In U7, the sediment becomes highly organic (loss-on-ignition 40–70%), Corylus, Alnus, Salix, Quercus, Ulmus, Pinus, and Plantago maritima increase, and Betula, Empetrum, Cyperaceae, and Poaceae percentages decrease. The aquatic vegetation rapidly increases and is totally dominated by Isoëtes lacustris and Nymphaea.

Although the lack of 14C dates permits no influx estimates, U7 indicates further vegetational closing and the development of fertile soils. Copses and wooded areas of Corylus, Betula, Populus, Salix, Alnus, Lonicera, and Viburnum developed locally. On the other hand, the representation of Pinus and broad-leaf trees may reflect forest establishment on the mainland. At Utsira, light-demanding vegetation such as dwarf-shrub heaths (Empetrum, Calluna) and grass communities were widespread. The expanding Plantago maritima may be an ancestor to the present P. maritima associations NW of Øvre Kvildaugaunya (Nordhagen 1923; Stokka 1971), whereas the Calluna vegetation formed early bridgeheads for the later dominance of Calluna heaths on the mainland (Kaland 1979). Interesting is one macrofossil find of Osmunda regalis (Hilary Birks, pers. comm.), today absent from Utsira. Together with spore finds (Fig. 5), this shows the local presence of Osmunda from late U6 and throughout U7. The Utsira records join other postglacial finds in W. Norway (Tjemsland 1983; Prösch-Danielsen 1984; Danielsen 1986), showing that Osmunda once had a wider range than its present relict distribution (Bjørndalen 1987).

Climatic history

Paz U1a (Oldest Dryas). No reliable information about the exact temperature conditions is available in this period. If not secondarily represented, the single-grain occurrences of Calluna, Filippenda, Parnassia, and Myriophyllum alterniflorum indicate a July mean of about 7–10°C (Kolstrup 1980). Well-represented reworked pollen and mineral-soil taxa suggest widespread soil erosion and cryoturbation. The causal factors may have included cold winters (Atkinson et al. 1987), strong winds (COHMAP 1988) and/or low snowfall, causing little snow cover and thus exposing soil to disturbances such as frost, freeze–thaw activity, and outwash (see Paus 1989a). The cooling effect of the surrounding ocean with meltwater (Lehman et al. 1990) was probably strong during the summers, whereas in winter the ocean may have been ice-covered (Ruddiman & McIntyre 1981). In this period, the vicinity of glacier may have contributed to wind activity (Nickling & Brazel 1985) far stronger than at present at Utsira.

Paz U1b+U2 (early/middle Bølling). At the U1a/U1b transition, decreasing reworked pollen and mineral-soil taxa and expanding grasslands reflect the onset of soil stabilization. Occurrences of Hippophäe, Typha latifolia (if not long-distance dispersed), and Lycopodiella inundata suggest a rising July mean to at least 12–14°C (Iversen 1954; Skre 1979; Kolstrup 1980) which compares to present conditions. Otherwise, a July mean of 10°C or more is shown by Nymphaea, Sanguisorba officinalis, and Myriophyllum spicatum (Kolstrup 1980). Probably also the winters became milder (Atkinson et al. 1987), and winds weakened as the deglaciation progressed. The changes in U1b+U2, initiated at about 13,000 BP represent the Bølling climatic amelioration and are associated with the retreat of the Atlantic polar front and a flow of warm Atlantic water into the Norwegian Sea (Mangerud 1977; Ruddiman & McIntyre 1981). In this period, the Late-glacial thermal maximum may have been reached (Atkinson et al. 1987; Vorren et al. 1988).

Paz U3 (late Bølling). Vegetation break-up, degradation of humus soil communities, and increases in reworked pollen and eutrophic aquatic taxa are interpreted as reflecting increased soil disturbance and erosion initiated by climatic deterioration. These changes, occurring about 12,300 BP if reliably interpolated, are correlated with ‘Older Dryas (Ie)’ events documented elsewhere (e.g. Mangerud 1980; Björck 1984; Gaillard 1985; Perez-Obiol 1988; Vorren et al. 1988; Paus 1989a).

The U3 event was probably not caused by
changes in summer temperature. As in U2 a July mean of at least 12–14°C is indicated by Typha latifolia (also recorded in the Sandvikvatn 'Older Dryas', paz S3b, c; Paus 1988), Hippophaë, and Lycopodiella inundata. Drought is another possibility (Kolstrup 1982). However, the relatively warm summers, combined with postulated ice readvances slightly older than 12,000 BP in W. Norway (Mangerud 1980), and the local persistence of moisture-demanding communities (see above) contradict reduced precipitation as an explanation. On the other hand, drought could have been caused by colder winters and/or stronger winds. Increased wind activity enlarged the areas of little or no snow-cover, thereby exposing vegetation and soil to frost activity and water deficiency (see Kolstrup 1982; Paus 1989a).

Paz U4 (Allerød s.l.). — The increases in total pollen influx, humus soil vegetation, and loss-on-ignition reflect the edaphic and vegetational responses to ameliorating climate. As no distinct changes in July mean temperature can be traced, the climatic improvement may have involved milder winters and/or weaker wind activity. In late U4, finds of Typha latifolia, Solanum dulcamara, and Echium indicate the July mean to be at least 12–14°C (Iversen 1954; Skrø 1979; Kolstrup 1980), the same as the inferred temperature for U2 and U3.

But, if the local July mean was 12–14°C throughout Bøling/Allerød, why did birch forests, which can develop with a July mean of about 10°C (Iversen 1954; Sjør 1971), not appear locally? A non-climatic reason for this apparent contradiction could be that tree birches did not reach Utsira by chance. However, in spite of the lack of tree-birch macrofossils (Hilary Birks, pers. comm.), Betula influx is sufficiently high that it may indicate the local presence of scattered trees. The inconsistency could also be explained edaphically. Humus accumulation, necessary for forest establishment (but not for single-birch occurrences; see Fægri 1934; Vetaas 1986) was delayed or prevented in exposed sites and in so-called Artemisia sites on coarse-textured substrata (Pennington 1986). Both types of sites characterize Utsira. Nevertheless, Juniperus and Urtica occurrences in the Allerød, in addition to representation of Filipendula throughout the Late-glacial, indicate that fertile humus-rich soils developed locally. Lastly, perhaps the temperature reconstruction could be based on long-distance representation of the warm temperature indicators. However, the entomophilous Solanum dulcamara (two grains in one level) and the tiny Lycopodiella inundata with limited spore-dispersal capacity, may indicate local conditions. On the other hand, these indicators could take advantage of the topography, finding protection in depressions and slopes. They therefore give microclimatic information (Iversen 1954). Tree birches were probably prevented from local forest establishment by a less favourable macroclimate involving, for example, sea spray and/or strong winds with their additional cooling and drying effects.

In U4, climatic instability is indicated. Minima in total pollen influx and Salix between ca. 11,400 and ca. 11,200 BP (early U4b) suggest a short-lasting climatic oscillation unfavourable to humus soil vegetation. A similar climatic change is weakly indicated at level 189 cm in U4a (interpolated to ca 11,750 BP) by corresponding minima in total pollen influx and Salix in addition to a district maximum in the mineral-soil taxon Artemisia. These U4a records are, however, onespectrum events and could be coincidental.

Nevertheless, two short-lasting climatic deteriorations within the Allerød are also shown in N. Rogaland and occur about 11,800–11,700 BP and 11,300 BP, respectively (Paus 1988, 1989a). The U4 episodes are correlated with these N. Rogaland events involving colder winters, stronger winds and/or drought (Paus 1988, 1989a, b) and appearing as fine-scale parallels to the 'Older Dryas (1c)' and YD deteriorations. Similarly, two cooler Allerød phases are recorded in Schleswig-Holstein (Usinger 1985).

Paz U5 (Younger Dryas). — The YD climatic shift involved a southern readvance of the Atlantic polar front (Ruddiman & McIntyre 1981) and drops in summer and winter temperatures in NW Europe (Rind et al. 1986; Atkinson et al. 1987). At Utsira this resulted in stronger soil erosion and increasing open-ground vegetation. But even if Salix-shrub vegetation declined, some humus-soil vegetation (with Empetrum, Juniperus, Filipendula, Urtica) persisted. In total, the YD vegetational change at Utsira was less marked than on the N. Rogaland mainland (Paus 1988, 1989b). The exposed island of Utsira, already under stress from an unfavourable climate before the YD climatic shift, may have supported a vegetation at some distance from ecotones and with a high
inertia to change (Smith 1965). In addition, because of its westerly position, Utsira was only to a minor extent, if at all, influenced climatically by the readvancing ice on the mainland (see Fig. 1).

Well-represented *Myriophyllum alterniflorum* throughout U5 indicates a July mean of 10°C or more (Kolstrup 1980). In the last half of U5, from ca. 10,500 BP (interpolated), the July mean seems to have increased to at least 12–14°C, according to finds of *Hydrocotyle vulgaris*, *Hippophaë, Lycopodiella inundata*, and *Typha latifolia* (Iversen 1954; Skre 1979; Kolstrup 1980). Probably these are early manifestations of the climatic amelioration associated with the onset of the Holocene. In Scandinavia, similar early dates of this ‘Holocene’ improvement are recorded from S. Rogaland (Paus 1989b) and S. Sweden (Bjørck & Möller 1987).

Apparently in contradiction, the Utsira sediments shift at this summer temperature rise to silty clay with low loss-on-ignition (steadily decreasing from 13 to 3%; Fig. 3). Usually, such Late-glacial sediments are connected with cold periods, soil erosion, and low organic production. However, the sediment accumulation is slow (Fig. 2) and the content of corroded (but determinable) pollen is high, especially in the upper part, indicating rapid degradation of organic material. This may be ascribed to the suggested warmer conditions, warming and saturating the shallow lake with oxygen. Similar oxidized sediments are found in the Holocene in shallow lakes or lake margins elsewhere in W. Norway (P. E. Kaland pers. comm.). Often these sediments are diatomites, whereas the Utsira late YD/early PB layer shows an abundance of other algae such as *Botryococcus* and *Pediastrum* spp. Sparse and corroded diatom fragments were observed, however (during tephra analysis). Similarly, diatom deficiency in oxidized Late-glacial sediments, probably as a result of strong corrosion, is reported from Vancouver Island, Canada (C. Erichsen pers. comm.).

**Paz U6 and U7 (early Holocene).** After some delay, the vegetation reacts to the Holocene climatic amelioration by developing a complete cover, and the silt/clay deposition ceases. From late U6 and throughout U7 the local presence of *Corylus* indicates a July mean of at least 12–14°C (Skre 1979). In the same period, *Osmunda* suggests a local July mean of at least 14–16°C and a January mean above 0°C, according to its present distribution in Norway (Laaksonen 1979; Lid 1985). This could demonstrate a rise in the winter temperature and a change to more oceanic conditions, as recorded in the early Holocene in S. Sweden (Lemdahl 1988). However, elsewhere in Scandinavia in areas with a July mean above 16°C, *Osmunda* tolerates a January mean down to −4 to −5°C (Laaksonen 1979; Lid 1985).

**Plant geography**

Due to limited identification precision to species, only 46 of the 106 Late-glacial pollen and spore taxa are phytogeographically classifiable. Following Hultén (1950), Berglund (1966), and Paus (1988), these are grouped into elements as shown in Fig. 7. For the total Late Weichselian, the major plant-geographical patterns are dominant boreal-circumpolar species (e.g. *Betula nana*, *Parnassia palustris*) and frequent arctic-alpine (e.g. *Koenigia islandica*, *Selaginella selaginoides*) and eurasiotic elements (e.g. *Helianthemum, Sanguisorba officinalis*). Oceanic s.l. (e.g. *Montia fontana, Plantago maritima*), and a few continental (*Hippophaë, Armeria maritima*) and boreal-alpine species (e.g. *Myricaria germanica*) are found. In contrast to the other Late-glacial Rogaland studies (Paus 1988, 1989a, b), there are no pollen records of the arctic *Papaver radicatum*-type (but its seeds have been found below U1, Hilary Birks, pers. comm.). Similar plant-geographical patterns occur for the local periods and for the new arrivals within each period (Fig. 7). However, continental elements are absent in U1, i.e. before the willow-shrub and *Empetrum* expansions that reflect the closing of vegetational cover. Also characteristic is the frequency of oceanic elements among the new arrivals within U2+U3+U4.

The boreal-circumpolar, arctic-alpine, and eurasiotic species were also the most abundant elsewhere in the NW European Late-glacial (Mitchell 1954; Berglund 1966; Paus 1988, 1989a, b). Utsira differs in the distinct dominance of boreal-circumpolar elements. Furthermore, at Utsira the highest values of oceanic plants are recorded. However, the sparse calculation basis for the Utsira frequencies prevents any close phytogeographical comparison with other sites.

Totally, the Utsira pollen diagram is poorer in number of taxa than the other diagrams from the
sites included in the Late-glacial project (Paus 1988, 1989a, b). This is not only a result of the lower number of pollen counted at Utsira. The Liastemmen diagram (Paus 1989a) is, for example, the most species rich, though the $\Sigma$P mean per spectrum and total $\Sigma$P in the diagram are distinctly lower than at Sandvikvatn (Paus 1988) and Eigebakken (Paus 1989b). A list of species lacking in the Utsira diagram but present in at least one of the other sites included in my project, mainly comprises plants of the following three categories: (1) Trees or shrubs such as Sorbus, Prunus, Viburnum, Frangula alnus, Rhamnus catharticus. (2) Calciphilous herbs such as Primula scandinavica, Gypsophila fastigiata/repens, Anthyllis vulneraria, Sanguisorba minor. (3) Herbs demanding fertile humus soils, such as Trollius europaeus, Pleurospermum austriacum, Mercurialis perennis, Polemonium caeruleum, Valeriana. I do not think these missing species are manifestations of migrational barriers (see Fridriksson 1975). Besides, absence from the diagram of these entomophilous species could demonstrate local scarcity rather than local absence. Most likely, the species lacking at Utsira indicate a reduced vigour of taller shrubs, humus-soil vegetation, and calciphilous plants compared to the Late-glacial vegetation on the Rogaland mainland. This is a result of a harsh climate that was unfavourable to woody vegetation and humus-soil development, and to lime-deficient bedrock and rapid erosion of soil (see above). Lime deficiency is also demonstrated by sparse Younger Dryas finds of Dryas octopetala, more frequently found throughout the Late-glacial elsewhere in NW Europe.

Acknowledgements. — I thank Svein Østerhus and Lodvar Mathiasen for assistance during field work, Jan Berge for preparing the pollen samples, and Siri Herland for drawing most of the figures. My sincere thanks to Hilary and John Birks for critically reading and correcting the manuscript.

Manuscript received February 1990

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