Quaternary stratigraphy of Norden, a proposal for terminology and classification

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Principles and terminology for classification of the Quaternary are discussed, including lithostratigraphy, biostratigraphy, morphostratigraphy, climatostratigraphy and chronostratigraphy. The main conclusion is a proposal for a common chronostratigraphical classification of the Quaternary in Norden (and partly continental NW Europe). The Quaternary is subdivided into the Pleistocene and the Holocene Series. The Pleistocene is further subdivided into several provisional stages (Weichselian, Eemian, etc.), based on the sequence of glacials/interglacials, but with the boundaries preferably defined by stratotypes. The Late Weichselian and the Flandrian (Holocene) are subdivided into chronozones (Bølling, Older Dryas, Allerød, Younger Dryas, Preboreal, Boreal, Atlantic, Subboreal, Subatlantic) with the boundaries defined in conventional radiocarbon years.

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A symposium on stratigraphical terminology and the classification of the Quaternary in Norden, organized by Dr. Risto Aario, was held during the 11th Winter Meeting of Nordic (Danish, Finnish, Swedish, Norwegian and Icelandic) Geologists in Oulu, Finland, in January 1974. The main aim of the symposium was to reach an agreement on a more uniform application of international terminology in Norden.

During the symposium a written report was presented by Mangerud (1973), and oral introductions were given by Andersen, Berglund and

Mangerud. Scientists representing the principal Quaternary Departments in Norden, and the main disciplines of Quaternary studies, participated. The opinions expressed were therefore assumed to be representative of Nordic Quaternary geologists. At the symposium it was suggested that the present authors should prepare a joint proposal, mainly based on the results from the symposium. The first draft for the chapter on the chronostratigraphy of the Pleistocene has been written by Andersen, for the chronostratigraphy of the Late Weichselian by Berglund, and for the other chapters by Mangerud, based on his earlier report. The proposals are, however, the responsibility of all the authors.

The terminology and the principles for stratigraphical classification during research in the Quaternary of Norden have developed largely independently of international rules. Mangerud (1970b, 1973) has discussed and recommended the application of the results reached by the International Subcommission on Stratigraphic Classification, a commission in the International Union of Geological Sciences. The results of the subcommission have recently been published (Hedberg ed. 1970a, 1970b, 1971a, 1971b, 1972a, 1972b), and we propose that these are applied as far as possible also to the Quaternary of Norden.

Lithostratigraphy

Formal lithostratigraphical units have been very little used in Norden. Such units were, however, used for lacustrine sediments by Mangerud (1970b), for glacigenic sediments by Mangerud & Skreden (1972), and for marine sediments by Mörner (1971).

For correlations, lithostratigraphy will probably be of major importance only in a few cases. In our opinion, however, lithostratigraphical units should be used to a much greater extent in the future than they have been in the past, for instance in connection with studies of till beds, marine transgression sediments, Baltic Sea sediments, etc.

Biostratigraphy

In Norden, biostratigraphical units have been defined on the basis of molluscs, foraminifera, diatoms and pollen. We do not intend to summarize all these classifications, merely put forward some proposals for terminology.

Mollusc zones

In eastern Norway, Brøgger (1900–1901) described stratigraphical units based on molluscs (summarized by O. Holtedahl 1960). He used terms like *Yoldia* Clay, *Arca* Clay etc., which are combinations of biostratigraphical (*Yoldia, Arca)* and lithostratigraphical (Clay) terms. Correct terms would be *Yoldia* Zone, *Arca* Zone, etc. However, the names of the taxons have also changed, and therefore, according to Hedberg (op.cit.), the correct term for the *Yoldia* Clay is *Portlandia* Zone, or preferably *Portlandia arctica* Zone.

Similar terms were used by A. Jessen (1899, summarized by Hansen 1965, pp. 49–50) for northern Denmark, e.g. Older *Yoldia* Clay, Younger *Yoldia* Clay, *Saxicava* Sand and *Zirphaea* Beds. On the Swedish west coast Asklund (1936) described a complete sequence of Late Weichselian mollusc zones. They were named 'Zones' but with climatological prefixes, such as 'High glacial' and 'Boreal', i.e. a combination of biostratigraphical and climatostratigraphical terms. In the Baltic area *Ancylus* Clay and *Littorina* Clay have been used for sediments deposited during the *Ancylus* and *Littorina* phases respectively. There is obviously a biostratigraphic influence on the lithostratigraphic as well as the chronostratigraphic terminology which should be avoided. There is also a need for revision of the Holocene mollusc biostratigraphy of the Baltic Sea.

Foraminiferal zones

Feyling-Hanssen (1964) defined foraminiferal zones in the Oslofjord area, and designated the zones with letters (A–G). He also named some of the zones after the dominating species, i.e. the *Bulimina marginata* Zone, for which a completely adequate term would possibly be *Bulimina marginata* Acme-zone. The other zones could also have been named. It is of great importance, however, that these zones are clearly defined biostratigraphical units, and therefore do not cause confusion. From southwestern Norway and northern Denmark Weichselian foraminiferal zones are described as assemblage zones (Feyling-Hanssen et al. 1971).

Diatom zones

Study of the diatom flora in Holocene Baltic sediments is a classical field of research in Sweden and Finland. Diatom assemblages characterizing sediments deposited in waters of varying salinity have been described. In this way a series of diatom zones were described by Sundelin (1919), Thomasson (1927, 1935), and used by others, i.e. Florin (1944), Berglund (1964), Donner (1964), as combined biostratigraphic and chronostratigraphic units. Thomasson (1927, 1935) described the *Gyrosigma* phase and the *Echineis* phase as units preceding the *Ancylus* time, Sundelin (1919) the *Mastogloia* time and the *Clypeus* time as transitional phases between the *Ancylus* and the *Littorina* time. The *Mastogloia* phase (and *Mastogloia* Sea) is still used as a synonym for the Early *Littorina* phase. However, diatom as well as mollusc names should be restricted to biostratigraphic zones – possibly with a correlation between the two systems. In this respect there is also a lack of information on which to base such a correlation.

Pollen zones

Earlier the biostratigraphy in a limnic-terrestrial environment was based on macrofossils, mainly fruits, seeds, wood remains etc. As early as 1841 Steenstrup described four Holocene zones on this basis: Aspen-, Pine-, Oak- and Alder-zones. They were based on biostratigraphy but used also for chronostratigraphy. Similarly Andersson (1896) used the zonation: Dryas-, Birch-, Pine-, Oak- and Spruce-zones, when he described the history of the Swedish vegetation.

Lennart von Post (1916, 1967) developed the analysis of pollen into a statistical method extremely useful for biostratigraphic correlation throughout the whole Quaternary. The method was originally used for relative chronology by geologists and later it was developed by botanists into a fine instrument for the interpretation of vegetational changes or ecosystem successions. The most widely used pollen zone systems for the Late Weichselian and the Holocene in Norden was that devised by Knud Jessen in Denmark (K. Jessen 1935, 1938). Similar zone systems were described by Nilsson (1935) for southern Sweden and Fægri (1935, 1940) for southwestern Norway. The zones were described as pollen assemblage zones, which were given numbers easily used in pollen diagrams, probably first applied by von Post (1925). These so-called pollen floristic zone systems were correlated with geologic and archaeologic chronologies and used as independent chronologies (e.g. Nilsson 1935:554, 1965, cf. Håkansson 1971a:486; Hansen 1965:58; B. G. Andersen 1965:122; Lundqvist 1965:156; Donner 1965:264). According to Nilsson (1948a, b) the pollen zones could be correlated between southern Sweden, Denmark and Germany due to a presumed synchronism within the area. Jessen's zone system was applied to south-central Sweden (Fries 1951), to Finland (Sauramo 1949, 1958; Donner 1951) and to Norway (Fægri 1954; Hafsten 1956). Meanwhile, Jessen's system was modified and introduced also into central Europe by Firbas (1949). In 1953 (Fægri 1954:237) Scandinavian pollen analysts agreed to use Jessen's pollen zones for the Late Weichselian and the Holocene throughout the area. This marked an important step forward, as pollen zones were the most precise method for correlation available at the time. In this way the biostratigraphic pollen zone systems developed into synonymous chronostratigraphic systems. However, this led to a false picture due to the lack of an absolute chronology. The radiocarbon method did not provide dates until the 1960's. Zone boundaries based on the spread of immigrating species can of course be expected to be metachronous. This was proved for the *Corylus* expansion in southern Scandinavia (Berglund 1966a:110; Hafsten 1969), for *Picea* in Finland (Aario 1965) and for *Picea* in the whole of Norden (Moe 1970).

Recently the extensive use of Jessen's zones has been criticized (Hafsten 1969, 1970; Mangerud 1970b; West 1970; Donner 1971; Birks 1973:280). The main objection is that several of the zones are not recognizable outside limited areas. For instance, Jessen's zone IX is characterized by the immigration of *Carpinus* and *Fagus*. The former species is not found in Norway, and *Fagus* has a very restricted occurrence. Nevertheless, Jessen's zone IX is widely used also in Norway, the zone being identified on climatostratigraphical or chronostratigraphical criteria. Jessen's zone system is therefore not used exclusively as a biostratigraphical classification, but rather as a combination of biostratigraphical, climatostratigraphical and chronostratigraphical classifications. For the present-day need of precision, this is not satisfactory.

The international rules (Hedberg ed. 1971a) also apply to pollen zones. In the case of Holocene diagrams these rules were probably first applied by Cushing (1967) in Minnesota, U.S.A., and in Norden by Mangerud (1970b), Donner (1971), Hyvärinen (1972, 1973) and Vorren (1972, 1973). For the Isle of Skye in Great Britain, Birks (1973:273–281, 325 ff.) has strictly applied the rules.

The main experience and philosophy behind the proposal of the International Subcommission on Stratigraphic Classification (Hedberg ed. 1971a) is the evolution and extinction of taxons, mainly of marine habitats. Biostratigraphical units based on such criteria will only be found in one stratigraphical position, and usually have a wide geographical extension. Pollen zones in the Late Quaternary are to the contrary mainly based on the geographical migration of terrestrial plants, mainly tree species. These zones, therefore, might be repeated in a sequence, and generally the zones will have a very limited geographical extension. The latter is especially the case in Norden, because of its very differentiated topography and climate. Some modifications of the rules for the pre-Quaternary stratigraphy have to be made. A solution of some of these problems might be the definition of regional pollen assemblage zones, as proposed for Finland by Donner (1971). However, present-day pollen diagrams are generally not satisfactory for such definitions. We need an extensive collaboration for (1) the definitions of biostratigraphic reference areas, (2) thorough investigations of palaeoecological standard profiles (preferably lake sediments within the reference areas), (3) correlation between regional biostratigraphy and the proposed general chronostratigraphy.

In pollen studies, the most used type of zones have been assemblage-zones. For ecological interpretations, the use of pollen assemblage zones has clear advantages, as the pollen assemblage will reflect plant communities. From a stratigraphical point of view one might, however, prefer other types of zones, where the boundaries are defined by only one criterion. For instance an interval-zone, the *Corylus* rise/*Alnus* rise Interval-zone, defined by the rational limit of *Corylus* and *Alnus,* should be unambiguous and recognizable in large parts of Europe.

The discussion above refers mainly to the biostratigraphy of the Late Weichselian and the Holocene deposits. However, the same aspects are valid for older Quaternary deposits. In recent investigations of pre-Weichselian and Weichselian sequences of Denmark, S. T. Andersen (1961:17–18, 1965) used numbered zones which correspond to pollen assemblage zones.

Morphostratigraphy

For many Late Pleistocene and Holocene sediments, the landforms are one of the major characteristics. Frye & Willman (1962) therefore suggested the recognition of morphostratigraphic units, though Richmond (1959) and Flint (1971:200) are of the opinion that landforms should not be used as stratigraphic units. No doubt, landforms do differ from the general stratigraphic idea of superposition of strata. Nevertheless, landforms originated at various moments in geologic time. For instance, a succession of shorelines at different levels, or a series of end moraines behind each other, are obvious bases for relative dating of geological events. The differences between morphostratigraphical and traditional stratigraphical units are, firstly, that landforms are abstract surfaces, while traditional units are real bodies of rock strata, and secondly, that in traditional stratigraphy the younger units are found in vertical sequences above the older ones, while in morphostratigraphy the younger units often occur in lateral sequences at lower levels than the older ones. The important point for us is that in some cases it may be desirable to classify geological events on the basis of their landforms. We therefore recognize a morphostratigraphical classification.

Moraines, as landforms, are generally associated with a geographical name, for instance the Ra moraines, the Central Swedish moraines and the Salpausselkä moraines. The same terms might be used for the morphostratigraphic units, only in capitalized form (Aarseth & Mangerud 1974), for example the Ra Moraines. In Sweden the sequence of Late Weichselian 'moraine lines' could be named the Fjärås Moraines, the Moslätt-Berghem Moraines, the Central Swedish Moraines (cf. Mörner 1969). Similarly the Minnesund Delta, the Lavik Sandur, etc. could be used for other morphostratigraphical units. The term Substage is often used in the same sense. This is, however, a chronostratigraphical term and should not be used in connection with end-moraines.

No generally accepted terminology exists for shorelines. Very often they are designated by letters and/or numbers, for instance Marthinussen (1960) in northern Norway used S_1–S_{18}, P_1–P_{12} and N_1–N_9. He also used the term Tapes line, which is generally used in Norway for shorelines connected with the Tapes transgression. The numbered Holocene transgression schemes of the Kattegat (e.g. Mörner 1969, with PTM 1–10) and the Baltic Sea (e.g. Berglund 1971b, with Littorina I–VI) refer to the morphologically recognized shorelines as well as the transgression sediments. Perhaps also shorelines should be named from type localities.

Climatostratigraphy

A major characteristic of the Quaternary was the great variations in climate, which have also naturally been a main base for stratigraphic subdivision.

Synchronism of climatostratigraphical boundaries has been much discussed and has been briefly mentioned above. We will not discuss this further here, but merely state that in principle such boundaries are not strictly synchronous because climatic changes are complex, and because we do not observe the climatic changes themselves, only the impact of the changes on vegetation, fauna, glaciers, oceans, sediments etc. The question of synchronism is of course also a question of precision. For the pre-Weichselian, time-correlations based on climatic interpretations are certainly more precise than other methods of correlation available today. This, however, will not always be the case for the Holocene and the Late Weichselian.

We will therefore maintain the distinction between climatostratigraphical units and chronostratigraphical units (Am. Com. Stratigraphic Nom. 1961; Mangerud 1970b). Flint (1971:373) has recently changed the concept of climatostratigraphy to glacial stratigraphy; in our opinion this is a restriction which is not desirable. We propose the definition that a climatostratigraphical unit is a stratigraphical unit with the boundaries defined by geological indications of climatic changes. Thus, the boundaries may be time-transgressive.

Many of the stratigraphical units of the Quaternary – glacials, interglacials, interstadials, etc. – were primarily defined as climatostratigraphical units in the sense outlined above. In case they are changed to chronostratigraphical units, they should preferably be defined by stratotypes in such a way that the boundaries, at least in theory, are synchronous levels. Furthermore, the terms glacials (for instance the Weichsel Glacial) and interglacials should only be used either in a climatostratigraphical or in an informal sense. In formal chronostratigraphical units only the chronostratigraphical term (e.g. the Weichselian Stage) should be used, because a chronostratigraphical unit is defined by certain stratigraphical horizons, and climatic aspects such as glaciation etc., in principle, are not included in the definition.

In Norden many stratigraphical units have originally been defined as climatostratigraphical in the sense used in this paper. We recommend that use of climatostratigraphical definitions be generally restricted; chronostratigrahpical units should receive preference. We therefore propose (see Chronostratigraphy) redefinition of the Late Weichselian classification (Bölling, Older Dryas etc.), and of the Holocene Blytt-Sernander classification (Preboreal, Boreal etc.), which by many investigators has been used as a climatostratigraphical classification, so that all these units can be considered chronozones.

Chronostratigraphy

'*A chronostratigraphic unit* is a body of rock strata which is unified by representing the rocks formed during a *specific interval of geologic time*' (Hedberg ed. 1971b:6). Thus the boundaries of chronostratigraphical units are, in theory, everywhere of the same age.

The aim of chronostratigraphical classification is the establishment of a hierarchical sequence of chronostratigraphical units, both of regional and world-wide scope, which can be accepted generally as a standard scale (Hedberg ed. 1971b:17). The classification scheme for the Cenozoic in Norden given in Table 1 will be discussed in more detail in the following chapters. The units of higher rank, at least erathem, system and series, are of world-wide application, and agreement should be attained through international commissions. Our comments, therefore, are simply arguments for international discourse. Similarly, stages, and partly also chronozones, are valid in Europe outside Norden.

As a vast number of classifications of lithostratigraphical, biostratigraphical, morphostratigraphical or climatostratigraphical nature have been applied to the Quaternary, we are of the opinion that a hierarchical chronostratigraphical classification is indispensable for the unification of these many independent systems.

Definition of boundaries

Boundaries for chronostratigraphical units are usually defined by means of stratotypes. We suggest that this practice is applied for units of stage rank or higher. In the Pleistocene, stratotypes may also be preferred for boundaries of units of lower rank.

For the Late Weichselian and the Holocene, however, we propose definition of chronozone-boundaries directly in conventional radiocarbon years.

The International Subcommission on Stratigraphic Classification (Hedberg ed. 1970b:15) ascertains that definitions in terms of radiometric ages would indeed accord with the concept of chronostratigraphical units. The commission has, however, two major objections to such definitions:

(1) '. . ., these age determinations cannot yet be made with sufficient accuracy or in enough different kinds of rocks to make it practicable to define many of our currently used chronostratigraphic terms wholly on the basis of radiometrically determined time-spans in years'.

(2) 'Likewise, the establishment now of a new scheme of chronostratigraphic units based only on equal intervals of time in millions of years, as some have proposed, would cause us to lose much of the value of the chronostratigraphic work of the past' (Hedberg ed. 1970b:15).

However, none of these objections have any real significance for our proposal, for the following reasons:

(1) Nearly all the Late Weichselian and Holocene sediments may directly or indirectly be dated by the radiocarbon method. Actually, the correlations within this time-span are so dependent on radiocarbon datings that if a sediment cannot be correlated to a classification defined in radiocarbon years, then it cannot be correlated to any chronostratigraphical classification defined by stratotypes.

(2) In Norden no chronostratigraphical classification of the Late Weichselian and Holocene exists showing satisfactory definitions of the respective boundaries. New definitions are therefore necessary in any case, and instead of proposing a new classification, we propose only precise definitions of already well established terms, leaving the age of the boundaries as close as possible to the tradition of the last few decades.

Time scales

Absolute ages of Late Weichselian and Holocene sediments can be obtained by several methods: radiocarbon dating, varve chronology, dendrochronology, historical documents, and others. Basically, all dates are related to one of two scales, namely radiocarbon years or calendar years.

According to international agreements all radiocarbon dates are calculated on the basis of the Libby C^{14} half-life of 5568 (or 5570) years. The years in which the resulting time-scale is expressed are usually called conventional radiocarbon-years. Also other variables, such as recent activity, isotope fractionation, etc., have been standardized internationally. For marine shells, however, some varying calculation-procedures are used (Mangerud 1972: 144–146). Some years ago (cf. Olsson et al. 1962; Olsson 1968) new measurements of the half-life indicated that 5730 years is a more correct value than 5570 years and the new value was recommended for use (Godwin 1962). Some conventional radiocarbon ages were therefore recalculated according to the new half-life (Nilsson 1964; Berglund 1966a, b and others). In view of the results on the long-term variations in the length of the radiocarbon years (see below), we propose that a separate correction for the new half-life should no longer be applied.

The year A.D. 1950 is used in all cases as the reference year (zero-year) for calculation of radiocarbon years. However, many scientists, in particular archeologists, recalculate dates to refer to the birth of Christ. We find this prac-

Geo-chronologic	Era	Period	Epoch	Age
Chrono-stratigraphic	Erathem	System	Series	Stage
	Cenozoic	Quaternary	Holocene	Flandrian +
			Pleistocene	Weichselian +
				Eemian +
				Saalian s.l. +
				Holsteinian +
				Elsterian + 'Interglacial III' 'Glacial B' +
				'Interglacial II'= Harreskovian +
				'Glacial A' +
				'Interglacial I'= Osterholzian
				Menapian Several stages in the Netherlands and North Germany
		Tertiary	Pliocene Miocene Oligocene Eocene Paleocene	

Table 1. The generally used subdivision of the Cenozoic Erathem into systems and series. A provisional subdivision in stages for continental NW-Europe is also shown. In this column the horizontal lines indicate recognizable stage boundaries, and crosses stages represented in Denmark. References (for stages): S. T. Andersen 1965; Cepek 1967; Erd 1970; Goedeke et al. 1966; Grüger 1968; Menke 1968a, 1972; Zagwijn 1960; Zagwijn et al. 1971; Zagwijn 1973.

tice illogical, as this date is the zero-year for the calendar year system. Radiocarbon years, however, are not calendar years, as may be demonstrated by the fact that 4000 radiocarbon years B.C. are probably equivalent to almost 5000 calendar-years B.C.

Our knowledge of the relationship between radiocarbon years and calendar years has greatly increased during the last few years, mainly through correlations of dendrochronology and radiocarbon dates of the tree-rings (Suess 1970; Damon et el. 1970; Ralph & Michael 1970). Conventional radiocarbon years can be converted directly to dendrochronological years (supposed to be indentical to calendar years) by means of a diagram (e.g. Olsson 1972: Fig. 1). However, the measurements do not cover the whole Holocene, and the results can be further refined.

We propose that only the following two timescales be used for the Late Weichselian and the Holocene, and that different zero-years be used in each case:

(1) One scale in conventional radiocarbon years ($T_{1/2}$ = 5568 years), using 1950 as zero-year.

(2) One scale in calendar years, using the birth of Christ as zero-year. This scale and reference year should preferably always be used for calendar years, whether these are found by historical documents, correction of radiocarbon years, varve chronology or other methods.

The Cenozoic Erathem

The most common subdivision of the Cenozoic Erathem is shown in Table 1. The Cenozoic is subdivided into the Tertiary and Quaternary Systems. The Quaternary is further subdivided into the Pleistocene Series and the Holocene Series. This classification has been proposed by the International Subcommission on Stratigraphic Classification (Hedberg ed. 1971b:19), and generally accepted in Norden.

During the last few years, however, several authors (for instance West 1968:224–225; Flint 1971:384) have proposed that the terms Tertiary and Quaternary should be discarded as stratigraphical terms; that the Pleistocene Series should include all post-Pliocene strata; and consequently that the Holocene Series should be discarded. This latter opinion has been supported in Norden by Hafsten (1969, 1970). Menke (1972) suggested a subdivision of the Quaternary into Cenocene (Känozän) and Pleistocene, without a Holocene. Menke's (1972) Cenocene would be a natural and useful unit, but it has not yet received general approval. In future a subdivision of the Quaternary into Cenocene-Pleistocene-Holocene should be seriously considered.

There are, no doubt, arguments in favour of the suggested changes. There are, however, also arguments in favour of the established classification (for example Fairbridge 1968:526). Tradition is perhaps the most important argument. Therefore, we recommend that the classification proposed by the International Subcommission on Stratigraphic Classification should be generally accepted and used.

The position of the Pleistocene/Holocene boundary has been very much discussed, and placed in a different way in different countries. In Norden, the boundary has generally been put at the Younger Dryas/Preboreal boundary, which is approximately 10,000 radiocarbon years B.P. At the congress of the International Union of Quaternary Research (INQUA) in Paris 1969 (Hageman 1969) this level has also been proposed to be the global boundary, and the search for a stratotype continues. At the meeting of the INQUA Commission for the study of the Holocene 1971, southern Sweden was chosen as the type area (cf. the preliminary report by Mörner ed. 1973), but a good type section has not yet been found.

The Pleistocene Series

The pre-Weichselian stages. – As climatic change is a main feature of the Pleistocene, subdivisions in Northern Europe have been based on indications of major climatic changes. Intervals characterized by evidence of a predominantly cold climate have been called glacials, and predominantly warm intervals were termed interglacials. The Pleistocene has thus been considered a sequence of alternating glacials and interglacials.

The glacials were characterized by a cold climate and deforestation of a wide area. However, correlation of these glacials with the Scandinavian ice sheets is not possible in all cases, mainly due to incomplete records in Norden. Continuous sequences are not known in all cases, and their identification and delimitation are sometimes problematic.

The interglacials are characterized by evidence of a warm climate and continuous forest successions. Furthermore, eustatically conditioned marine transgressions have been recognized in several cases. They can be correlated by means of pollen analysis or other methods, at least in restricted areas, and can be arranged in a stratigraphic sequence.

The glacials contain several geologically recognizable smaller units, which have been called stadials and interstadials. The interglacials and the interstadials are warm phases of two different orders, and their distinctiveness is possibly only a matter of duration. In most cases it has been agreed which units should have the rank of interglacials and which should have the rank of interstadials.

A common glacial/interglacial chronology has been used to a wide extent in the Netherlands, northern Germany and Denmark. Elster, Saale and Weichsel, the old German names for glaciations, have been used for glacials, and names such as Eem and Holstein, originally coined for marine deposits, have been adopted for interglacials. Newly discovered units have been named in various ways, in some cases after the locality first described.

A formal chronostratigraphy for the Pleistocene Series in the British Isles was established by Mitchell et al. (1973). The traditional names for glacials and interglacials were used for stage names. Stratotypes were selected from various publications, and certain pollen zone boundaries were used for stage boundaries.

The British Pleistocene chronostratigraphy cannot be transferred to the continent because of difficulties in correlation. A chronostratigraphic terminology for Norden, which must be common to the adjacent regions of (at least) northern Germany and the Netherlands, has not been established. Hence, we consider it desirable that a formal chronostratigraphy is worked out for continental northwest Europe. Such a chronostratigraphy must be based on the glacial/interglacial chronology, but it will be necessary to define stages and stage boundaries by means of stratotypes. Some difficulties will probably arise due to gaps in the record, and it may be necessary to define local stages in cases of doubt, but in our opinion an ultimate goal should be a common terminology. A provisional chronostratigraphic subdivision of the Pleistocene in continental northwest Europe is shown in Table 1.

Deposits from several Pleistocene stages are known in Denmark (Table 1, S. T. Andersen 1965). Deposits from the Eemian have been recognized in Norway (Mangerud 1970a) and Sweden (Lundqvist 1971; Berglund & Lagerlund 1974).

The Weichselian Stage. – A proposal for subdivisions of the Weichselian Stage is shown in Table 3. We propose that the Early Weichselian/Middle Weichselian Substage boundary is placed at the Early Glacial/Pleniglacial boundary of van der Hammen et al. (1971), and that the Middle Weichselian/Late Weichselian Substage boundary is placed at a level corresponding to 13,000 radiocarbon years B.P. (see below).

We propose that the stadials and interstadials formerly recognized within the Weichselian should be redefined as chronozones in a formal chronostratigraphy. At present, however, the terminology is incomplete.

Within the Early Weichselian Substage the Amersfoort and the Brörup interstadials are known from the Netherlands, and Denmark (S. T. Andersen et al. 1960; S. T. Andersen 1961; Zagwijn 1963), Brørup and Odderade from Germany (Averdick 1967; Menke 1970) and Brørup probably also from Sweden and Finland (Lundqvist 1967, 1971; Berglund & Lagerlund 1974; Korpela 1969). The Amersfoort interstadial was characterized by forest in the Netherlands and shrub vegetation in Denmark, and the Brørup and the Odderade interstadials by forest. During the Brørup interstadial subarctic forest could even have grown in northern Scandinavia.

Within the Middle Weichselian Substage the Moershoofd, Hengelo and Denekamp interstadials with intervening stadials were recognized in the Netherlands and dated at respectively 50,000, 38,000 and 30,000 B.P. (van der Hammen et al. 1971). In the Netherlands none of these warm phases had associated forest. They were preceded and succeeded by intervals with extremely cold conditions (polar desert). All these stadials and interstadials may be redefined as chronozones in a formal chronostratigraphy.

The Late Weichselian Substage. – The Middle Weichselian/Late Weichselian Substage boundary is identical to the Pleniglacial/Late-glacial boundary of van der Hammen et al. (1971). This boundary has been dated to about 13,000 B.P. (van der Hammen et al. 1971; Menke 1968b). We propose to accept this date as the definition of the discussed boundary. The Late Weichselian Substage therefore will correspond to the classical Late-glacial in northwestern Europe. It comprises the Oldest Dryas, Bølling, Older Dryas, Allerød and Younger Dryas 'periods' (Hartz & Milthers 1901; Iversen 1942, 1954, 1967, 1973). The term Late-glacial (and also Post-glacial) should, however, not be used for formal stratigraphic units. Van der Hammen (1957) placed the lower boundary of the Bølling interstadial at the lower boundary of the Late-glacial. Recent dating of the Zirphaea beds in northern Denmark now extends their age back to nearly 13,000 B.P. (Krog & Tauber, in press), and it seems natural to extend the Bølling back to that date in accordance with the classification adopted in the Netherlands (van der Hammen et al. 1971). However, it is well known that the biostratigraphic 'birch zone', named Bølling by Iversen (1942), has a lower boundary dated to ca. 12,300 B.P. In Denmark, southern Sweden and southern Norway where the Late Weichselian chronology developed, the old climato-biostratigraphic zones will correspond to the proposed chronozones. The Bølling Chronozone thus comprises the Oldest Dryas and Bølling periods or pollen zones I a and I b of Iversen (1954), pollen zones DR1 and BÖ of Nilsson (1961) and Brøndmyr Interstadial and preceding pollen zones (I, II and III) of Fægri (1940). The Older Dryas Chronozone comprises the Older Dryas period or pollen zone Ic of Iversen and DR2 of Nilsson. The Allerød Chronozone comprises the Allerød period or pollen zone II of K. Jessen

Table 2. Radiocarbon dates of Late Weichselian boundaries. Only dates of biostratigraphically thoroughly studied profiles through limnic-terrestrial sediments have been selected. The samples refer to levels at, just below or above the discussed boundaries.

Boundary	Age	No.	Site	Reference
Bølling/Older Dryas	12,070±140	K-542	Usselo, Netherlands	van der Hammen 1951 Tauber 1960b
–	12,100±140	K-708	Witow, Poland	Wasylikowa 1964 Tauber 1962
–	11,900±180	K-706	–	–
Older Dryas/Allerød	11,890±140	K-1973	Bølling, Denmark	Stockmarr unpubl.
–	11,770±215	St-2508	Klinchögkärret, Sweden	Mörner 1969
–	11,740±170	St-1423	Lösensjön, Sweden	Berglund 1966a, Engstrand 1967
–	11,730±150	Lu-210	Trummen, Sweden	Håkansson 1970
–	12,070±180	T-672	Blomøy, Norway	Mangerud 1970b, Nydal et al. 1970
Allerød/Younger Dryas	10,970±120	K-101	Ruds Vedby, Denmark	Krog 1954, Tauber 1964
–	10,970±300	K-110	Bølling, Denmark	Tauber 1960a
–	11,090±130	K-1902	–	Stockmarr unpubl.
–	10,915±230	St-2528	Älgare mosse, Sweden	Mörner 1969
–	11,110±115	Lu-406	Björkeröds mosse, Sweden	Berglund 1971a, Håkansson 1971b
–	11,060±100	Lu-209	Trummen, Sweden	Håkansson 1970
–	10,800±300	T-152	Bröndmyra, Norway	Chanda 1965 Nydal 1960
–	10,940±180	T-624	Blomøy, Norway	Mangerud 1970b, Nydal et al. 1970
Younger Dryas/Preboreal	10,400±130	K-1903	Bølling, Denmark	Stockmarr unpubl.
–	9,920±160	K-1604	Gravlev, Denmark	–
–	9,915±180	St-2165	Älgare mosse, Sweden	Mörner 1969
–	10,120±100	Lu-738	Näckrosdammen,	Berglund 1973
	10,250±120	Lu-740	Sweden	Håkansson in prep.
–	10,320±105	Lu-408	Björkeröds	Berglund 1971a,
	10,160±105	Lu-409	mosse, Sweden	Håkansson 1971b
–	9,920±150	St-805	Ageröds mosse, Sweden	Nilsson 1964 Östlund & Engstrand 1963
–	9,850±100	Lu-121	Ranviken, Sweden	Digerfeldt 1973 Håkansson 1969
–	10,170±230	St-1337	Hallarums	Berglund 1966a,
	10,000±170	St-1336	mosse, Sweden	Engstrand 1967
–	10,170±160	St-1778	Slättmossen,	Berglund 1966a,
	9,700±150	St-1847	Sweden	Engstrand 1967
–	10,360±105	Lu-208	Trummen,	Digerfeldt 1972
	10,230±105	Lu-207	Sweden	Håkansson 1970

(1935) and AL of Nilsson, and the Younger Dryas Chronozone comprises the Younger Dryas period or pollen zone III of Jessen and DR3 of Nilsson.

All Late Weichselian chronozone boundaries seem to be climatically conditioned within southern Scandinavia, since there is a close correlation between biostratigraphic changes and deglaciation patterns (cf. Mörner 1969:182; Tauber 1970; Mangerud 1970b; Berglund 1971a). As stated above, we propose that the chronozone boundaries should be defined by radiocarbon ages. The definitions are based on dates from non-calcareous lake sediments in southern Scandinavia – the only area of Norden which was ice-free during the greater part

Table 3. Provisional chronostratigraphic subdivision of the Weichselian and the Flandrian in continental NW-Europe.

Geo-chronologic	Age	Subage	Chron	Definitions of boundaries in conventional radiocarbon years B.P.
Chrono-stratigraphic	Stage	Substage	Chronozone	
	Flandrian	Late Flandrian	Subatlantic	2500
		Middle Flandrian	Subboreal	5000
			Atlantic	8000
		Early Flandrian	Boreal	9000
			Preboreal	10,000
	Weichselian	Late Weichselian	Younger Dryas	11,000
			Allerød	11,800
			Older Dryas	12,000
			Bølling	13,000
		Middle Weichselian	? Denekamp ? Hengelo ? Moershoofd ?	
		Early Weichselian	Odderade ? Brørup ? Amersfoort ?	

of the Late Weichselian. However, for the oldest boundary we must refer to dates from central Europe. Therefore, southern Scandinavia, comprising Denmark, southern Norway and southern Sweden, will be an informal 'type area' for the Late Weichselian chronostratigraphy.

Compilations of dates of the boundaries have been given previously by B. G. Andersen (1968: 76–77), Mörner (1969:175–177), Mangerud (1970b: Fig. 11), Berglund (1966a:113–118, 1971a:13) and others. We have critically selected dates of limnic-terrestrial material related to the boundaries (Table 2) and these form the basis for our proposed definitions of the boundaries (Table 3) as follows: the lower boundary of the Bølling Chronozone is defined at 13,000 conventional radiocarbon years B.P.; the boundary between Bølling and Older Dryas Chronozones is defined at 12,000 B.P.; the Older Dryas/Allerød Chronozone boundary at 11,800 B.P.; the Allerød/Younger Dryas Chronozone boundary at 11,000 B.P.; and the Younger Dryas/Preboreal Chronozone boundary is preliminarily defined at 10,000 B.P.

Hyvärinen (1973:91) has given a survey of several radiocarbon dates for Early Holocene biostratigraphic zone boundaries in eastern Finland. The boundary of the *Artemisia* zone and the birch zone in southeastern Finland probably corresponds to the Younger Dryas/Preboreal chronozone boundary and is dated at 10,000 to 10,200 B.P. However, this area is situated close to the Salpausselkä moraines from the Younger Dryas, and there may be problems with the correlation of this area with southern Sweden.

In our proposal the upper boundary of the Late Weichselian is defined at 10,000 B.P., mainly because the Pleistocene/Holocene boundary will be fixed at that age. However, the dates mentioned above indicate that the generally used biostratigraphic boundary between the tundra and birch zones is slightly older in southern Scandinavia.

The Holocene Series

The Holocene has the rank of a series (Table 1), and could thus be subdivided into several stages. During the last few years, however, the most common practice has been to use the term Flandrian Stage, with a lower boundary at the Younger Dryas/Preboreal transition. In this usage the Flandrian Stage is identical to the Holocene Series, and two names are actually superfluous. Mörner (1972) argues that the Flandrian (interglacial) should end at the beginning of the next glacial, while the Holocene should include several interglacials and glacials. However, stratigraphy is not concerned with the classification of future events. Nevertheless, for convenience, we propose to accept the present use, with the Holocene and the Flandrian covering the same period, but having different rank (Table 1).

We propose that the Flandrian be subdivided into three substages, Early, Middle, and Late Flandrian (Table 3). The boundaries should be at the same level as the boundaries of the chronozones (see below). The Early Flandrian Substage includes the Preboreal and Boreal Chronozones, the Middle Flandrian includes the Atlantic and Subboreal, and the Late Flandrian Substage includes only the Subatlantic Chronozone.

The Flandrian Stage. – At present, no generally accepted chronostratigraphical classification of the Flandrian exists in Norden. The most used classification is the modified Blytt-Sernander scheme in Preboreal, Boreal, Atlantic, Subboreal and Subatlantic. We therefore propose that these well-established terms, with redefined boundaries, be used for formal chronostratigraphical units (chronozones). Since we propose a redefinition of the Blytt-Sernander terms, we will briefly review the original definitions.

The terms were introduced by Axel Blytt (1876a, b); he used them, however, exclusively for floral elements of the present-day vegetation of Norway (boreal plants, atlantic plants etc.). The relation to stratigraphy was the following: Blytt (1876a, b) assumed that these floral elements had immigrated during succeeding periods, the arctic plants first, the subatlantic latest. In view of their present distribution, he also assumed that the boreal and subboreal plants had immigrated during periods of continental climate, while the atlantic and subatlantic plants had immigrated during periods of oceanic climate. In Norwegian peat-bogs he found alternating layers of peat and stumps, and he related the peat-beds to the periods of oceanic climate and the stump-beds to the periods of continental climate (Blytt 1882a, b).

In all these pioneer-papers Blytt consistently restricted the terms boreal, atlantic, etc. to the present-day floral elements of Norway, and avoided use of the terms for stratigraphic units. He published a large number of papers during the 1880's, but seems to have maintained this distinction.

The earliest we have discovered the terms used for stratigraphy is in 1889 by Sernander (1899:199), where he uses the concepts of Blytt's 'atlantiska period' and Blytt's 'subboreala period', obviously connecting the terms atlantic, etc. to Blytt's descriptions of peat-bogs and his climatic interpretations. Later Sernander (1890: 17) used all Blytt's terms for succeeding periods, characterized by different climate, still referring to Blytt's investigations. This practice was then adopted by Blytt (1893), who in addition used the terms for the different layers he had described previously in the peat-bogs: the subatlantic peat-bed, the subboreal stump-bed, the atlantic peat-bed, etc. (translated from Blytt 1893:11).

So far, the meaning of the terms had changed without any real discussion or new definitions. A fundamental paper in establishing these terms as stratigraphic unit-terms is that of Sernander (1894). He stated that phyto-paleontological zones, such as the aspen-birch-horizon, cannot be assumed *a priori* to be time-synchronous over large areas, due to the migration-time of the species (Sernander 1894:4). Therefore he examined methods for improved determinations of contemporaneity of deposits, and concluded that changes of sea-level and climate were the best methods available. Concerning climatic changes, he refers to Blytt's theories, of which he accepted the main description of the climatic development, though he rejected (Sernander 1894:70) many of Blytt's interpretations and ideas.

In the peat-bogs of Gotland, Sernander (1894) found the same stratigraphy as Blytt had described from Norway. Therefore he (1894:71) used Blytt's terms (subatlantic, subboreal, etc.) for the different peat-beds, and also for the corresponding period. This publication (Sernander 1894) was later generally recognized as defining the 'Blytt-Sernander units', which soon after were widely used in Norden.

The term 'preboreal' was first used in a general way for the time before the boreal period (e.g. Erdtman 1921; Fægri 1935). Later 'preboreal' became restricted to the time interval between the Younger Dryas and Boreal (e.g. Fægri 1940), which has been the common practice the last decades.

During the last few decades the Blytt-Sernander terms have been used with varying meaning, and most researchers (e.g. Nilsson 1961:9) exclude the climatic interpretations. Many authors (e.g. Iversen 1967, 1973; Jørgensen 1963; Hafsten 1956, 1960; Danielsen 1970; Fries 1951, 1965; Berglund 1966a, b; Königsson 1968; Digerfeldt 1972; Donner 1963) also use the terms as synonyms for Jessen's or Nilsson's pollen zones, and therefore the boundaries are as asynchronous as the pollen-zone boundaries. One conclusion is indeed certain; at present no generally accepted definitions of the boundaries of the Blytt-Sernander units exist. Nevertheless, the units have mainly been applied as broadly synchronous zones (Table 4).

Most of the boundaries cited in Table 4 are based on compilations from both small and large areas, though the boundaries given by Nilsson (1964) and Berglund (1966b) are partly based on series of dates from a single sediment or peat core also thoroughly biostratigraphically studied. Such series of dates, which are important when dealing with Flandrian radiocarbon ages, are available from the following non-calcareous areas: Kongsmosen, SW Jutland, Denmark, 54 dates (Aaby unpublished); Agerøds mosse, Scania, Sweden, 33 dates (Nilsson 1964; Östlund & Engstrand 1963); Ranviken, Scania, Sweden, 25 dates (Digerfeldt 1973; Håkansson 1969); Hallarums mosse, Blekinge, Sweden, 26 dates (Berglund 1966b; Engstrand 1967; Olsson 1965); Trummen, Småland, Sweden, 30 dates (Digerfeldt 1972; Håkansson 1969, 1970).

Based mainly on the compilations in Table 4 and the mentioned series of dates, we propose the following definitions (Table 3) of chrono-

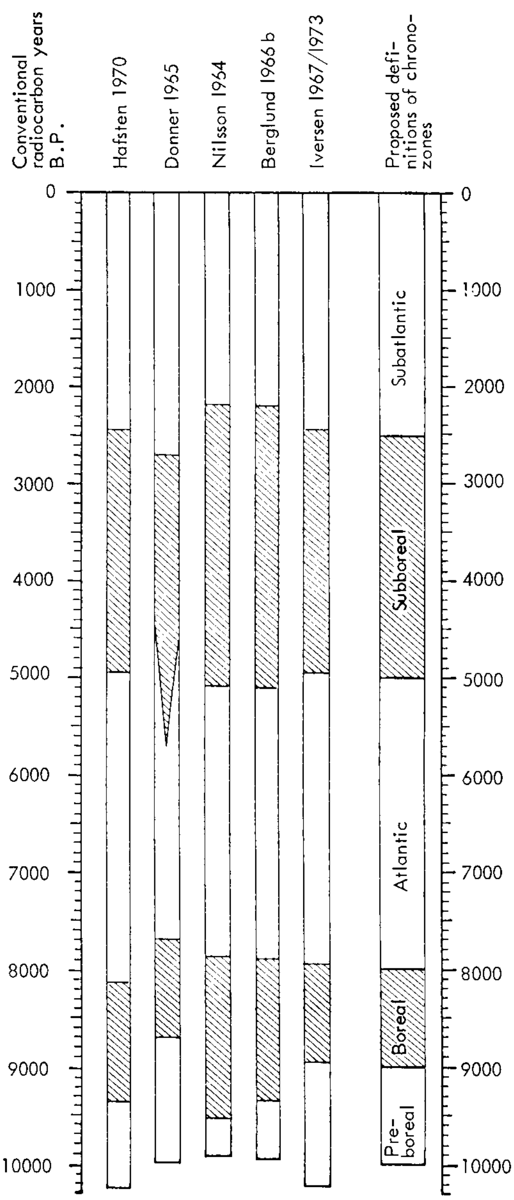

Table 4. The ages of the Blytt-Sernander zones, as given by some authors in Norden during the last decade. The boundaries of Nilsson 1964 and Berglund 1966b are recalculated to conventional radiocarbon years. Proposed definition of chronozones to the right. From Mangerud (1973: Fig. 5).

zone boundaries, retaining the Blytt-Sernander terms, and attempting to maintain the essential chronological meaning attached to them during the last few decades:

Table 5. Proposed subdivision of Flandrian chronozones.

Chronozone	Sub-division	Radiocarbon years B.P.
Subatlantic	Late	
		1000
	Middle	
		2000
	Early	
		2500
Subboreal	Late	
		3000
	Middle	
		4000
	Early	
		5000
Atlantic	Late	
		6000
	Middle	
		7000
	Early	
		8000
Boreal	Late	
		8500
	Early	
		9000
Preboreal	Late	
		9500
	Early	
		10,000

(1) The boundary between the Younger Dryas and Preboreal Chronozones is preliminarily defined at 10,000 radiocarbon years B.P. This boundary may later be referred to the stratotype for the Pleistocene/Holocene boundary, if this stratotype should be finally accepted according to the intention discussed above.

(2) The Preboreal/Boreal Chronozone boundary is defined at 9000 radiocarbon years B.P. Some dates indicate a shorter Preboreal, an alternative age for the boundary being 9500 B.P. However, for the majority of the area the proposed age is more relevant.

(3) The boundary between the Boreal and Atlantic Chronozones is defined at 8000 radiocarbon years B.P.

(4) The Atlantic/Subboreal Chronozone boundary is defined at 5000 radiocarbon years B.P. According to Olsson (1972: Fig. 1) this corresponds to 3600–4000 dendrochronological (calendar) years B.C.

(5) The Subboreal/Subatlantic Chronozone boundary is defined at 2500 radiocarbon years B.P. According to Olsson (1972) this corresponds to 600–800 dendrochronological (calendar) years B.C. According to these definitions the duration of the Subboreal Chronozone is 2500 radiocarbon years. This is, however, a period of 'long' radiocarbon years, and 2500 radiocarbon years will probably correspond to approximately 3000 calendar years.

To avoid confusion with previous usage the combined terms, e.g. Preboreal Chronozone should be used when referring to the present definitions.

Subdivision of the chronozones. – With present-day precision of Holocene stratigraphy, there will no doubt be a need for a subdivision of the chronozones. Probably it will be most convenient to define units of that rank locally. There is, however, also a need for a standardized subdivision, during, for instance, the planned registration of palaeobotanical data. Therefore we propose the subdivision shown in Table 5. We emphasize that the definitions of these units have no real geological basis, they are just subdivisions into reasonable time-units, possibly with the rank of Subchronozones.

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APPENDIX

Stratigraphic terms for Nordic languages compared to corresponding ones in English

English	*Norwegian*	*Swedish*	*Danish*	*Finnish*
chronostratigraphy	kronostratigrafi	kronostratigrafi	kronostratigrafi	kronostratigrafia
erathem	erathem	erathem	erathem	erathemi
system	system	system	system	systeemi
series	serie	serie	serie	sarja
stage	etasje	etage	etage	vaihe
substage	subetasje	subetage	subetage	alavaihe
chronozone	kronosone	kronozon	kronozone	kronovyöhyke
geochronology	geokronologi	geokronologi	geokronologi	geokronologia
era	æra	era	æra	maailmankausi
period	periode	period	periode	periodi
epoch	epoke	epok	epoke	epookki
age	alder	ålder	alder	ikä
subage	subalder	subålder	subalder	alaikä
chron	episode	episod	episode	episodi
Cenozoic	Kenozoikum	Kenozoikum	Kænozoikum	Kenotsooinen
Quaternary	Kvartær	Kvartär	Kvartær	Kvartääri
Pleistocene	Pleistocen	Pleistocen	Pleistocæn	Pleistoseeni
Holocene	Holocen	Holocen	Holocæn	Holoseeni
Elsterian	Elster	Elster	Elster	Elster
Holsteinian	Holstein	Holstein	Holstein	Holstein
Dömnitzian	Dömnitz	Dömnitz	Dömnitz	Dömnitz
Rügerian	Rügen	Rügen	Rügen	Rügen
Saalian	Saale	Saale	Saale	Saale
Eemian	Eem	Eem	Eem	Eem
Weichselian	Weichsel	Weichsel	Weichsel	Weichsel
Flandrian	Flandern	Flandern	Flandern	Flanderi
Early W./F.	Tidlig W./F.	Tidig W./F.	Tidlig W./F.	Varhais-W./F.
Middle W./F.	Mellom-	Mellan	Mellem	Keski-W./F.
Late W./F.	Sen	Sen	Sen	Myöhäis-W./F.
Amersfoort	Amersfoort	Amersfoort	Amersfoort	Amersfoort
Brørup	Brørup	Brørup	Brørup	Brørup
Odderade	Odderade	Odderade	Odderade	Odderade
Moershoofd	Moershoofd	Moershoofd	Moershoofd	Moershoofd
Hengelo	Hengelo	Hengelo	Hengelo	Hengelo
Denekamp	Denekamp	Denekamp	Denekamp	Denekamp
Bølling	Bølling	Bølling	Bølling	Bølling
Older Dryas	Eldre Dryas	Äldre Dryas	Ældre Dryas	Vanhempi Dryas
Allerød	Allerød	Allerød	Allerød	Allerød
Younger Dryas	Yngre Dryas	Yngre Dryas	Yngre Dryas	Nuorempi Dryas
Preboreal	Preboreal	Preboreal	Præboreal	Preborealikausi
Boreal	Boreal	Boreal	Boreal	Borealikausi
Atlantic	Atlantikum	Atlantikum	Atlantikum	Atlanttinen kausi
Subboreal	Subboreal	Subboreal	Subboreal	Subborealikausi
Subatlantic	Subatlantikum	Subatlantikum	Subatlantikum	Subatlanttinen kausi