A Late Quaternary Correlation Chart for Norway.[1]

By

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Abstract.

A correlation chart is presented containing the stratigraphical results of some selected Norwegian studies in the wide field of Quaternary geology. Studies of plant remains in bogs, pollen investigations, evidence of transgressions, shoreline displacement, registered by isolation of troughs from the sea during isostatic rise of the land mass, have all contributed to the columns of the chart. Furthermore, shoreline stages based upon occurrence of marine Mollusca in littoral sediments in Norwegian localities as well as in Spitsbergen, clay deposits in the Oslofjord area, subdivided by their content of marine Pelecypoda and Foraminifera, marginal moraine substages in southern Norway and in the northernmost part of the country have been plotted. A curve illustrating the variation in the height of the firn line in western Norway is also inserted.

Introduction.

The Blytt-Sernander sequence, which is to be found in the left part of the correlation chart, here presented, is assumed to be known to students of the Holocene all over the world, and may serve as an international standard to which the less known specific Norwegian columns can be referred. As an other international standard the *Danish pollen analytical zone system*, proposed by Knud Jessen (1935, 1938), is inserted and closely related to the modified Blytt-Sernander sequence. For the same purpose of international correlation the well-known terminology proposed by Gerard de Geer (1912), based upon studies of *varved clay*

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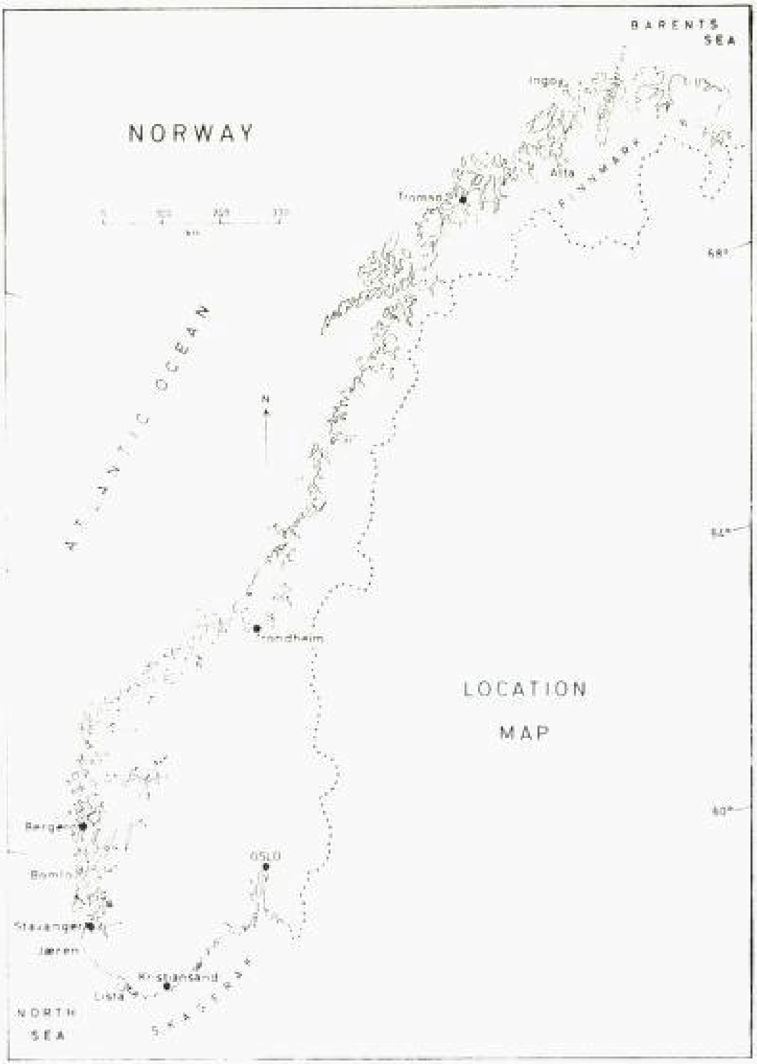

Figure 1. Norway, with the geographical names mentioned in the text.

chronology in Sweden, is to be found in the chart. De Geer used the terms *Late Glacial* and *Post Glacial* in a different way than the pollen stratigraphers use them to-day. The latter usage is found on the left side of the Blytt–Sernander sequence in the chart. In that column is also indicated the *Post Glacial Warm Interval,* in the concept of, i. a., Firbas

(1954), which is the same as the *Postglacial Hypsithermal Interval* of Deevey and Flint (1957), embracing the Boreal, Atlantic and Sub-Boreal of Blytt–Sernander (cp. Gams and Nordhagen, 1923, p. 293). The term *Post Glacial Warm Interval proper* is narrower, comprising only Atlantic and Sub-Boreal time.

To the left in the chart are listed the *Late Quarternary* epochs *Pleistocene* and *Holocene*. In accordance with general use (Cp. Woldstedt, 1954, p. 2) the borderline between the two epochs in the chart coalesces with the border between *Younger Dryas* and *Pre-Boreal*, i.e., the border between Late and Post Glacial in the concept of pollen stratigraphers.

The different zone borders in the chart have, if possible, been related to the *absolute time scale* under consideration of available radiocarbon datings (i. a., Gross, 1958; Radiocarbon Supplement, vol. 1, 1959, vol. 2, 1960; Radiocarbon, vol. 3, 1961, vol. 4, 1962). As to the dates for the pollen zone boundaries II/III, I/II, Ib/Ic, and Ia/Ib see especially *Tauber* (1960 a and b). For classifications not treated in the present short review, the reader is referred to Holtedahl's "Geology of Norway" (1960) or his "Norges Geologi" (1953) of which a Russian edition appeared in 1958.

The writer is grateful to Mrs. Kari Henningsmoen, The University of Oslo, and Dr. J. D. de Jong, The Geological Survey of Holland, who read the manuscript. He is also indepted to Dr. B. G. Andersen and Mr. M. Marthinussen, University of Oslo, who offered valuable suggestions about certain transgressions and moraine substages.

Pollen zones.

Fægri (1940, 1944, 1953) investigated the Late Quaternary development of vegetation and climate in two localities in south-western Norway, viz., the flat, moraine-covered coastland of Jæren south of Stavanger, and the rock island of Bømlo, between Stavanger and Bergen. Jæren was ice-free already in Late Pleistocene time.

Mainly from studies of size and morphology of *Betula* and *Salix* pollen Fægri recognized a series of Late Glacial climatic oscillations, zones I–VI in his designation. The lowermost samples were dominated by willows (*Salix herbacea*) and grasses. The subsequent development was characterized by a rapidly increased content of dwarf-birch pollen in the samples, and then by appearance of large-leaved birches. During zone VI (Jessen's zone III), Younger Dryas time, tundra conditions were reintroduced with heath (*Empetrum*), grass (*Graminae*) and sedge (*Cyper-*

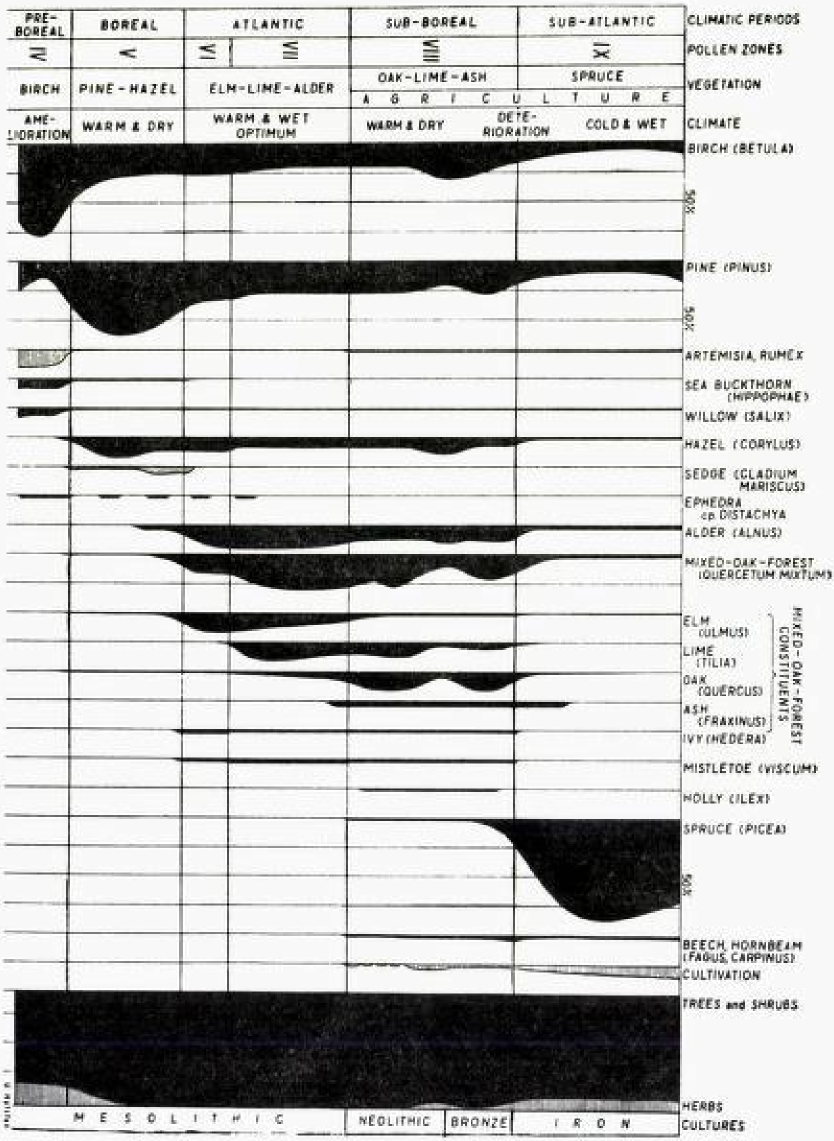

Figure 2. Standard pollen diagram for the inner Oslofjord area.
From Hafsten, 1960.

aceae). During Pre-Boreal time, characterized by the so-called Fini Glacial climatic amelioration, the dwarf-birch tundra was replaced by birch forests dominated by silver birch (*Betula verrucosa*). Due to violent melting the margin of the inland ice rapidly receded in still glaciated areas, and simultaneously an isostatic uplift took place at considerable rate. This is illustrated in the column of shoreline displacement at Oslo (Hafsten, 1956, 1959, 1960). A vegetation of heliophilous and rather thermophilous herbs and shrubs occupied such newly emerged areas during Pre-Boreal time. An abrupt change in vegetation took place at the transition to Boreal time. Pine (*Pinus silvestris*) and Hazel (*Corylus avellana*) to some extent replaced the birch, and the land was much more densly forested (Hafsten 1960). *Cladium mariscus*, known from three localities in Norway, dates back to the beginning of Boreal time. The mixed oak forest culminated in eastern Norway already during Atlantic time, in western Norway, however, during Sub-Boreal time. Other constituents of the vegetation development support the view that the climatic optimum in eastern Norway occurred in Atlantic time, whereas in western Norway it fell in Sub-Boreal time (Hafsten, 1960). Misteltoe (*Viscum*) seems to have had a continous distribution from the Mjøsa region, north of Oslo, along the south coast to Jæren. Water chestnut (*Trapa natans*) from Atlantic and early Sub-Boreal time has been found on both sides of the Oslofjord. – With Sub-Atlantic time a profound climatic deterioration took place. The sensitive trees were replaced by more hardy species, predominantly spruce (*Picea abies*). In the Oslofjord region this expansion of spruce was almost explosion-like (Hafsten, 1960).

The pollen analytical zone system of Jessen is now in general use among Norwegian pollen stratigraphers.

The earliest traces of man in Norway are *Mesolithic* reaching back into Boreal age probably even into Pre-Boreal. The *Komsa culture* in Finnmark, northern Norway, and the *Fosna culture* in western Norway belong here. Either of them are hunting cultures (Cp. Nummedal, 1924; Bøe and Nummedal, 1936). The younger *Nøstvet culture* extends into Sub-Boreal age (Brøgger, 1905). Agricultural land occupation dates back to the Atlantic/Sub-Boreal transition, and was probably introduced into southeastern Norway by immigration of a southerly farming population during the Danish Dolmen age (Hafsten, 1960, p. 459).

Shoreline displacement.

Phenomena proving displacements of the shoreline during the Quaternary period, especially during the Late Pleistocene and Holocene epochs, have been studied and discussed in Norway for more than one hundred years. A considerable number of observations and measurements have been brought together. A recent review of the activities in this field was given by Holtedahl (1960, p. 369) in his "Geology of Norway".

Hansen (1890, 1900) connected the problem of shoreline displacement with the ice-pressure theory of Jamieson (1865), and many papers dealing with shoreline displacement, positive and negative, as resulting from isostatic readjustment appeared, e. g., Helland (1900). Holmsen (1918) and Nansen (1922) brought into the discussion the importance of eustatic changes of sea level. These ideas formed the foundation for the comprehensive, wellknown shoreline studies carried out by the Finish geologist Tanner in northern Fennoscandia (e. g., 1930), and for similar studies in northern Norway by Grønlie (1940) and Undås (1938). The results of these investigations are not incorporated in the present correlation chart.

During many years Marthinussen (1945, 1960) studied *shorelines* in *Finnmark,* northern Norway. He separated three groups within the series of marine levels: Late Glacial lines, designated by S, Post Glacial lines, P, and Neo Glacial lines, N. In the correlation chart a few of these lines are listed. The designation *Tapes, I–IV*, has been used instead of N_9–N_6, and none of the P lines are plotted, except P_{12} which is synonymous with S_0, the so-called main line. The lines are placed in the column according to their age, which has been radiologically determined by the aid of marine shells from corresponding deposits. As illustrated by the chart, some lines correspond to marginal moraine stages, others to periods of *transgression*. To the right of the column with the transgressions is given the *shoreline displacement* for two localities in Finnmark, one outer, more periferal, the island of Ingøy, more than 71° n. lat., 24° e. long., and one situated, more centrally, Alta, 70° n. lat., 23° e. long. The more rapid land elevation toward central areas is clearly illustrated. The main line S_0, is on Ingøy situated approximately 2 m above present-day sea level whereas in Alta it is found 75 m above sea level.

In the Trondheim region, central Norway, *and the Oslo region,* southeastern Norway, Øyen (i.a., 1903, 1915) established a system of Holocene *shoreline stages* based upon occurrence of certain littoral molluscs in shore deposits. He found the highest marine limit at Skaadalen, Oslo to be 221 m above present-day sea level, characterized by *Mytilus edulis*. A sample of *Mytilus* shells from shore gravel at that locality, submitted by H. Rosendahl, was radiologically dated at 9680 $\pm$ 250 years before present (1950). The dating was carried out by R. Nydal of the Radiological dating laboratory in Trondheim. Successive lower stages in the shoreline displacement were named: *Portlandia stage* (*Portlandia arctica*, a small form), *Littorina stage* (*Littorina littorea*), *Pholas stage* (*Barnea candida*), *Mactra stage* (*Spisula solida* var. *elliptica*), *Tapes stage* (*Tapes decussatus*), *Trivia stage* (*Trivia arctica*), *Ostrea stage* (*Ostrea edulis*) and *Mya stage*, Recent (*Mya arenaria*). In the column for this system in the chart, an effort is made to place the borderlines between the stages in accordance with the heights given by Øyen. Øyen supposed a transgression to have taken place at the beginning of each stage in his system. It has not been possible to verify the existence of such transgressions by later studies. For this and other reasons Øyen's system was heavily critisized by Holtedahl (1924) and Hessland (1943). Short reviews of it are given by Feyling-Hanssen (1957, p. 16, 17) and Holtedahl (1960, p. 382–385).

In southwestern Norway, Bømlo and Jæren, Fægri (1940, 1944) traced the Late Quaternary *displacement of the shoreline by pollen-analytical investigation* of bog basins at different heights above present-day sea level. His results, with displacement diagrams, are summarized by Hafsten (1960, p. 453–458). In Bømlo Fægri estimated a marine limit at 32 m above present sea level, whereas in central Jæren it was situated at a height of 9 m. Both places three *transgressions*, intervals with a positive shift of the shoreline, were found to have taken place, one Late Pleistocene and two Holocene. The Late Pleistocene one, called the Alvevann transgression, seems to be slightly older than the Allerød interstadial. Andersen (1960, p. 97) assumed this transgression to have taken place in Bølling time, accordingly it is placed at Bølling level, with a " ?", in the column for *transgressions in Southwest Norway* in the chart. Andersen (1.c.) recorded a Late Pleistocene transgression from the *Norwegian south coast*, west of the city of Kristiansand, this is assumed to be of Allerød age.

Of the two Holocene transgressions recorded by Fægri, one occurred in Atlantic time, the other one at the transition between Atlantic time, the other one at the transition between Atlantic and Sub-Boreal. He estimated the total eustatic rise of sea level between the Boreal regression

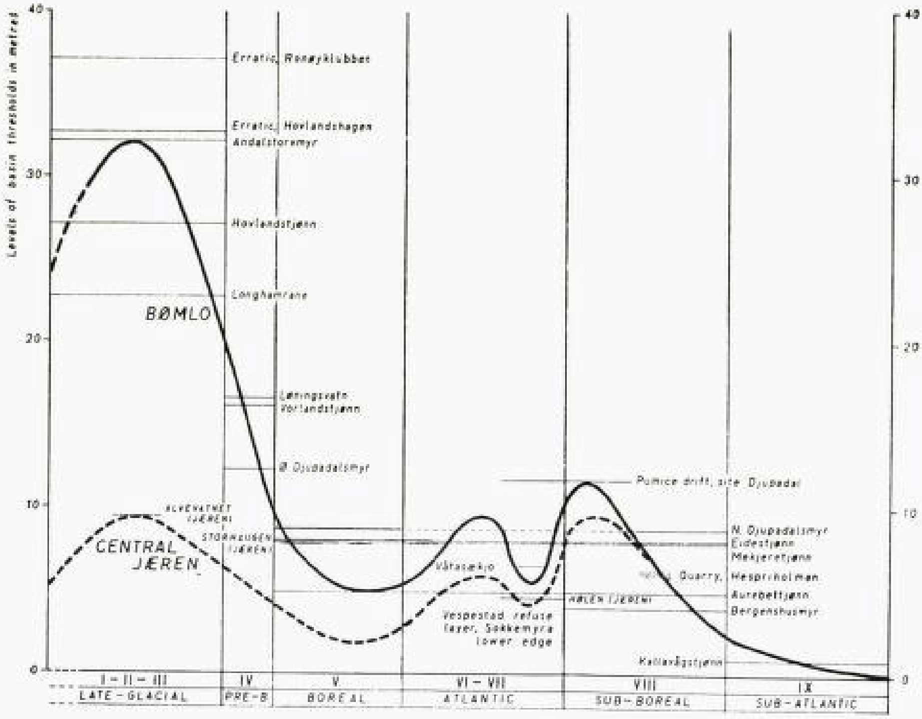

Figure 3. Diagrammatic representation of the Late Quaternary shoreline displacement in Jæren and Bømlo, constructed on the basis of Fægri's results (1940 and 1944). From Hafsten, 1960.

minimum and the Sub-Boreal transgression maximum as 8–9 m. Gabrielsen (1959, p. 1616–1617) found a transgression at Mandal, South Norway, to have started approximately 8800 years ago (Cp. Hafsten, 1958; Andersen, 1960, p. 98).

In the Oslo area, Southeast Norway, the Holocene shoreline displacement was investigated pollen-analytically by Holmsen (1920) and Hafsten (1956, 1959). There the shoreline shifted from 221 m above present sea level to its present position without any positive oscillations. The isostatic component in the relative movement outrivalled the eustatic one during the whole epoch. As seen from the height figures plotted in the chart (*Shoreline displacement at Oslo*), the shift was much more rapid during the older part of the Holocene than in the younger part of the epoch.

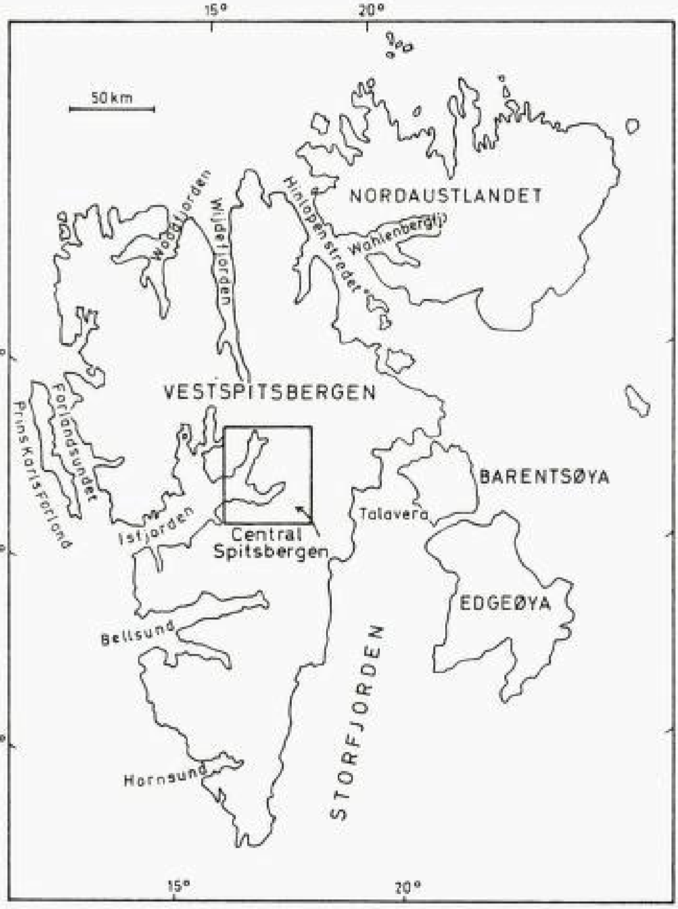

Figure 4. Sketch map of Spitsbergen.

It decreased from 11 m per century in Pre-Boreal time to 0.37 m in Sub-Atlantic time. Two thirds of the Holocene shoreline displacement had taken place before the beginning of Atlantic time (Hafsten, 1960, p. 457).

For the Billefjord and Kapp Wijk in *central Spitsbergen* Feyling-Hanssen (1955 a, b) established a Late Quaternary stratigraphical sequence based on studies of raised shorelines and fossil shells of marine molluscs and cirripeds in the deposits. Shorelines of marine origin were found up to 90 m, in the near-by Sassenfjord even up to 96 m, above present sea level. Marine shells were found up to 84,5 m a.s.l. Changes in faunal composition during a general negative shift of the shoreline made the following subdivision possible:

The *Late Glacial Cold interval* comprises the time in which the shoreline in the Billefjord moved from 90 m to 60 m above present day sea level. Only two species of marine molluscs were observed in the corresponding deposits, viz. *Saxicava* (*Hiatella*) *arctica* and *Mya truncata,* only scattered shells and fragments occurred.

The *Post Glacial Temperate interval* comprises the time during which the shoreline moved from 60 m to 40 m above present sea level. 14 new species (11 molusc species, 1 cirriped, 1 echinid and 1 calcareous algae) occurring in the corresponding deposits, among them *Chlamys islandica, Mytilus edulis, Serripes groenlandicus, Macoma calcarea, Littorina saxatilis, Balanus balanus.* The fauna suggests that the marine-climatic conditions of that interval were slightly more favourable than those prevailing in the area to-day. As the fauna of the terraces between 60 m and 40 m a.s.l. are predominated *Mya truncata,* these terraces were called *Mya terraces.*

The *Post Glacial Warm interval* is the period in which the shoreline in the Billefjord moved from 40 m to 3 m above present sea level. According to occurrences in the corresponding deposits 39 new species of molluscs and cirripeds immigrated to the inner Isfjord area during that period, among them 7 which now seem to be extinct in Spitsbergen waters, viz. *Heteranomia squamula, Modiolus modiolus* (= *Volsella modiolus*), *Arctica islandica* (= *Cyprina islandica*), *Zirfaea crispata, Emarginula fissura, Littorina littorea, Omalogyra atomus.* Consequently the marine-climatic conditions were decidedly better than those prevailing there to-day, probably similar to those now prevailing along the coasts of Finnmark and Iceland. As the fossil fauna of the littoral deposits between 40 m and 6 m a.s.l. is predominated by *Astarte borealis,* the terraces within that height interval were termed *Astarte terraces.* They were further divided into *Upper Astarte terraces,* from 40 m to 17 m a.s.l. and *Lower Astarte terraces,* from 17 m to 6 m a.s.l. Between 6 m and 3 m a.s.l. there occur littoral features which were termed *Mytilus terraces,* because *Mytilus edulis* predominates in most of them.

The *Sub-Recent interval* is the time in which the shoreline moved from 3 m a.s.l. to its present position. At these levels the Warm interval indicators have disappeared from the fossil fauna; even *Mytilus edulis* seems to have abandoned Spitsbergen waters. In very recent time this species seems to have reoccupied the area. A severe deterioration of the climate took place during the Sub-Recent interval.

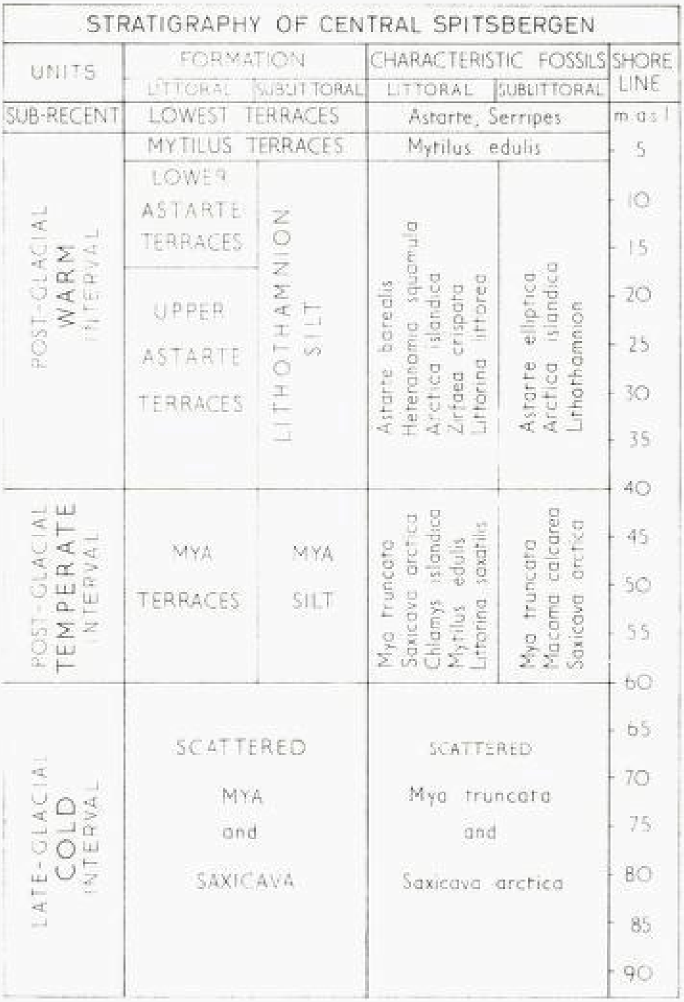

Figure 5. From Feyling-Hanssen, 1955.

These stratigraphical units of central Spitsbergen were correlated with the Late Quaternary horizons recognized in *West Greenland* by Laursen (1950): The *Post Glacial Warm interval* of central Spitsbergen corresponds to the *Horizon F* of West Greenland as proved by the occurrence of equivalent "warm" indicators in the fossil faunas of the two areas. Deposits with *Mytilus* and *Astarte* in King Oscar Fjord in *East Greenland* (Noe-Nygaard, 1932) also belong to that interval. The *Post Glacial*

Temperate interval of central Spitsbergen corresponds to the *Horizon E* in West Greenland and to deposits with *Chlamys, Mytilus, Saxicava* (*Hiatella*) and *Mya* in East Greenland. In all the three regions *Mytilus edulis* appears for the first time in these deposits. The *Late Glacial Cold interval* in central Spitsbergen is correlatable with *Horizon D* and *C*, probably also *Horizon B* and *D* of West Greenland. In the King Oscar Fjord area of East Greenland the only fossils found above the *Mytilus* bearing deposits were *Saxicava* (*Hiatella*) *arctica* and *Mya truncata*, i.e., a fauna uniform with that of the Late Glacial Cold interval in central Spitsbergen.

Radiocarbon datings of some shells from the Late Quaternary deposits of the Billefjord (Feyling-Hanssen and Olsson, 1959–1960) revealed that the main trend of the negative shift of the shoreline during the Holocene epoch in central Spitsbergen is very similar to that of the Oslo region, for example. There was an early part with rapid displacement, more than 2 m per century, and a late part in which the rate was less than a tenth of this. The rapid displacement occurred in Pre-Boreal and Boreal time. Similar shoreline displacement, similar in aspect, not in magnitude, were found in Nordaustlandet (the North-East Land) in Spitsbergen (Blake, 1960, Olsson and Blake, 1961) in Franz Joseph Land Гросвальд (Grosvald), Девирц (Devirtz) and Доъкуна (Doskina), 1961), in northern Canada (Farrand, 1962) and in Northeast Greenland (Washburn and Stuiver, 1962).

According to radiocarbon datings of samples of peat layers, one from Barentsøya (the Barents Island) and one from Skansbukta in the Billefjord, marine transgressions seems to have occurred in Spitsbergen, one 6 000 years and the other 4 800 years before present. (Feyling-Hanssen, 1964, in press). The samples were dated by I. Olsson (Cp. Olsson, Cazeneuve, Gustavson, and Karlén, 1961).

Marginal moraine substages.

The recession of the latest inland ice in the Oslofjord area northwards to the great lakes of Southeast Norway has been investigated during more than one hundred years, i.a., by Keilhau (1838), Kjerulf (1871), Brøgger (1900–1900), Holtedahl (1924, 1960), Holmsen (1951). A series of marginal substages has been traced, the most prominent one being represented by the Ra ridge. This ridge has been followed, almost continuously from the Swedish border to Moss, on the east side of the outer

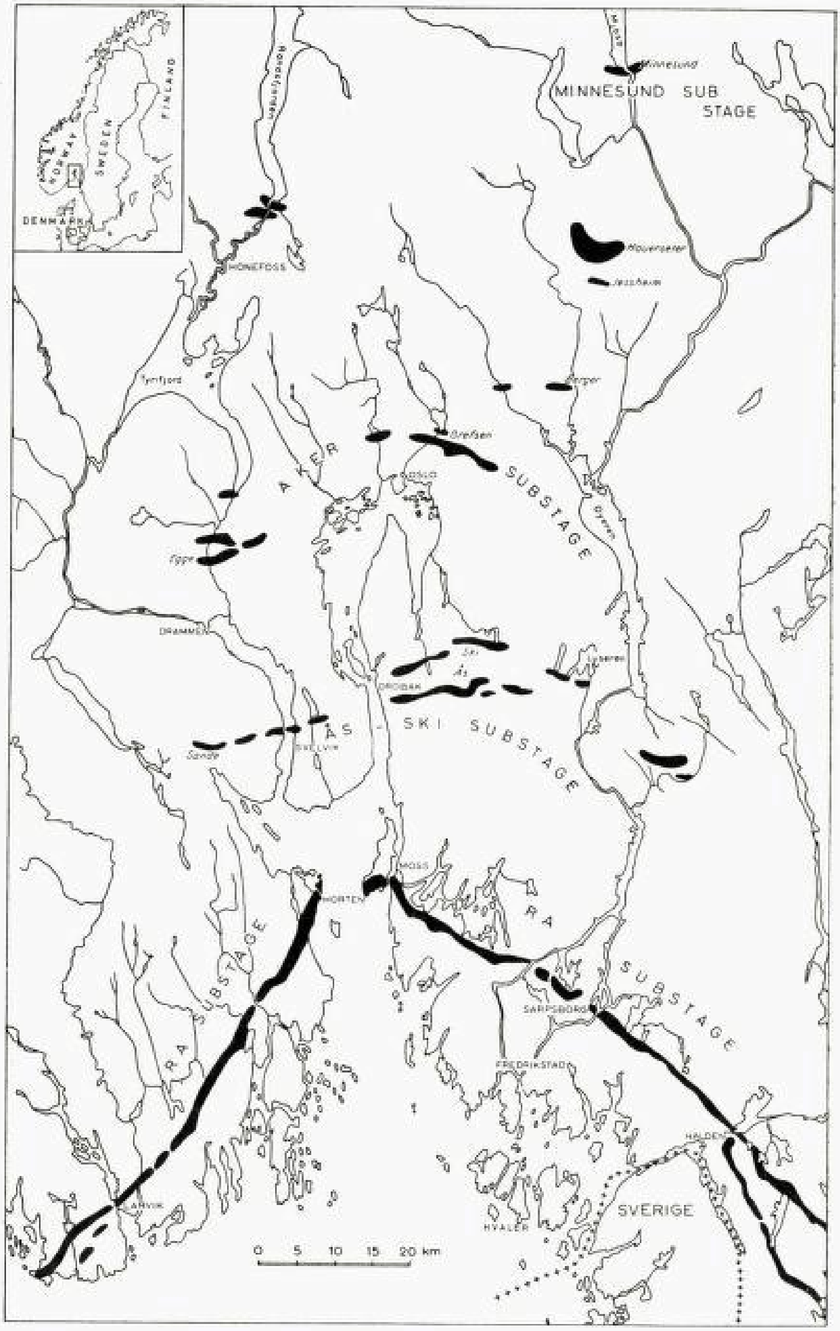

Figure 6. Marginal substages during the latest ice recession in the Oslofjord area of southeastern Norway. Redrawn from Holtedahl, 1953. From Feyling-Hanssen, 1957.

Oslofjord, from Horten, on the west side, to Jomfruland (Hansen, 1910), and from Arendal across southern Norway to the fjords east and north-east of the city of Stavanger (Andersen, 1954, 1960). This moraine sub-stage, the so-called Fennoscandian, is assumed to be of Younger Dryas age. A sample of fossil shells from marine sediments at Valle on the east side of the Oslofjord, supposed to have been deposited when the ice margin lay along the Ra line, has been radiologically dated at 10 700 $\pm$ 300 years before present (1950). A sample of shells from marine clay lying within the Ra ridge, at Larvik, was dated at 11 000 $\pm$ 250 years before present (samples submitted by Feyling-Hanssen, and dated by R. Nydal of the Radiological Dating Laboratory in Trondheim, cp. Nydal, 1962, p. 170).

Two older moraine substages are known to the south of the Ra ridge on both sides of the Oslofjord, viz., the Tjøme–Hvaler substage and the Tjølling–Slagen–Onsøy–Borge substage. They are not inserted in the correlation chart. From the Norwegian south coast Andersen (1960) recorded marginal moraines of three glacial substages older than the Ra substage, the oldest one being the Lista substage, which he supposes to be of Oldest Dryas age. The Spangereid substage is supposed to originate from the youngest part of Oldest Dryas time, and the Kristiansand sub-stage probably from Bølling–Older Dryas.

Of the two moraine substages younger than the Ra substage, moraines of the Aker substage are found, i.a., in the northern outskirts of the city of Oslo. The previously mentioned sample of *Mytilus* shells from littoral deposits corresponding to this substage (p.o) radiologically dated at 9680 $\pm$ 250 years before present indicates that the margin of the inland ice of the latest glaciation receded from the Ra moraine to the moraines of the Aker substage, in the Oslofjord district, a distance of 60 km, in less than 500 years. The Ås–Ski substage was geochronlogically (varved clay chronology) dated at 9940 years before present (E. H. de Geer, 1962). – The ice recession further northwards, between Oslo and the southern end of the lake Mjøsa, was traced by Holtedahl (1924) mainly by investigation of marginal deltas and terraces.

In Finnmark, North Norway, Marthinussen (1961) has mapped marginal moraines over long stretches and has recognized three substages, the most prominent of which is the Main stage (Hovedtrinnet). Moraines of this stage are at several localities connected with the Main line, S_0, in his shoreline system and supposed to be of Younger Dryas age. This was recently confirmed by radiological datings. The two older substages in Finnmark are marked by the Repparfjord moraines and the Outer Porsanger moraines. They are supposed to be of Older and Oldest Dryas age, respectively.

The moraines of the Main stage in Finnmark are correlatable with the moraines of the so-called Tromsø–Lyngen substage farther to the west in North Norway (Cp. Grønlie, 1940; Undaas, 1938).

Marine clay deposits.

Sars (1865) studied the fossils of marine clays and shell beds at several localities, primarily in the Oslofjord region and on the south side of the Trondheimsfjord. On the basis of their fossil content he divided the deposits in a Glacial and a Postglacial formation. The Glacial formation comprised Glacial shell beds and the so-called Mergellere (Marl clay), the Postglacial formation the Postglacial shell beds and the Muslinglere (Mussel clay) (Cp. Sars and Kjerulf, 1861).

1900–1901 Brøgger published a comprehensive paper dealing with the stratigraphy and paleoclimatic indications of the Late Quaternary deposits of the Oslofjord area. Littoral deposits were divided into 6 shell beds, the clay sediments into 10 main zones, on the basis of their content of fossil pelecypods (bivalves). The shell beds are (Brøgger 1900–1901, p. 650 a; 1905, p. 98) from older to younger, or highest to lowest: *Mytilus gravel, Upper Mya beds, Lower Mya beds* (with *Mya truncata*), *Upper Tapes beds* (in the 1900–1901-paper these beds were termed *Upper Ostrea beds,* the term *Upper Tapes beds* of 1905, p. 98, 124, comprises the beds previously termed *Upper Ostrea beds* and *Upper Tapes beds*), *Lower Tapes beds,* and *Recent beds.* This shell bed system is not embodied in our chart.

In 1905 (p. 123–126) Brøgger subdivided the shoreline displacement at Oslo during the main part of the Post Glacial Warm Interval (the «Post Glacial Warm Interval proper» by some authors) into 1) *Older Tapes age,* during which the shoreline shifted from 69–70 m to 45–48 m above its present position, 2) *Middle Tapes age,* during which the shoreline shifted from 45–48 m to 19–21 m, and 3) *Younger Tapes age,* during which it shifted from 19–21 m to 8–10 m above present-day sea level. The pelecypods *Tapes decussatus* and *Barnea* (*Pholas*) *candida* occurred in the shell beds of Older Tapes age (Upper Tapes beds), whereas during Middle Tapes age they seem to have disappeared from the area.

Brøgger's subdivision of the clay deposits is represented in the chart: The oldest unit is the *Yoldia clay,* which, according to Brøgger, was deposited outside, i.e., to the south of, the Ra ridge. Its index fossil is the thermophobous species *Portlandia arctica* (= *Yoldia arctica*). The hitherto oldest radiologically dated sample of Yoldia clay (sampled in Tønsberg brickwork by Brøgger and Øyen in the year of 1909 and recently submitted for dating by H. Rosendahl) had an age of 11 200 ± 200 years before present (Nydal, 1962, p. 168), and the hitherto youngest radiologically dated Yoldia clay sample (collected by Brøgger in Valle brickwork and submitted by Holtedahl, cp. Holtedahl, 1960, p. 375) was 9 950 ± 300 years old. The *Arca clay,* index fossil *Bathyarca glacialis* (= *Arca glacialis*), was deposited as the ice front retreated from the Ra to the Ås–Ski moraines. A sample of Arca clay from Søreng, Eidsberg was dated at 9 750 ± 250 years before present (Holtedahl, 1960, p. 376). During continued retreat of the ice margin to the moraines of the Aker substage the *Younger Arca- and Portlandia clay* was deposited, and during further retreat to the great lakes of Southeast Norway the *Youngest Arca- and Portlandia clay,* characteristic fossil *Yoldiella lenticula* (= *Portlandia lenticula*) was deposited. During improving climatic conditions the *Mytilus- and Cyprina clay,* characteristic fossils *Mytilus edulis* and *Arctica islandica* (= *Cyprina islandica*), the *Older Cardium clay* and the *Younger Cardium clay,* characteristic species *Cerastoderma edule* (= *Cardium edule*) came to rest. A sample of Older Cardium clay from the city of Oslo was radiologically dated at 9 100 ± 180 years before present (Holtedahl, 1960, p. 385). The unit *Upper Ostrea clay,* index fossil *Ostrea edulis* was discarded by Brøgger in his later paper (1905, p. 111, 124) and the term replaced with the older part of the subsequent *Isocardia clay* with *Glossus humanus* (= *Isocardia cor*) as characteristic species. The Isocardia clay, deposited at Oslo during shift of the shoreline from 69–70 m to 19–21 m above present-day sea level, was considered to represent the Post Glacial climatic optimum. The *Scrobicularia clay,* characteristic fossil *Scrobicularia plana,* was thought to have been deposited during shift of the shoreline at Oslo from 19 m to 9 m (8–10 m) above present sea level, thus representing the latest part of the Post Glacial Warm Interval (Brøgger, 1905, p. 98, 124). Consequently no part of that clay should be younger than 2 400 years b.p. However, two shell samples from Scrobicularia clay, recently dated (Holtedahl, 1960, p. 382, 385–386; Nydal, 1962, p. 161, 162, 168) were 2 050 ± 150 and 980 ± 100 C^{14}-years old. For this reason the Scrobicularia clay has been extended up to the Recent *Mya arenaria clay* in the chart. All C^{14} datings of samples from the Oslofjord area were carried out by R. Nydal.

Hessland (1943, p. 299, 300) called attention to the fact that *Scrobicularia plana* lives in brackish shallow-water whereas *Glossus humanus*, the index form of the Isocardia clay, prefers clear and saltier water of greater depth. He therefore suspected the Scrobicularia clay to be merely a shallow-water facies of the Isocardia clay.

Brøgger supposed that *Late Glacial* climatic conditions prevailed even during the deposition of the Older Cardium clay, his *Post Glacial* starts with the deposition of the Younger Cardium clay. In light of the above-mentioned C^{14} dating of an Older Cardium clay sample, this may be in quite good accordance with De Geer's classification. In his paper of 1900–1901 Brøgger applied the term *Recent* to the time after the immigration of *Mya arenaria* to the Oslofjord, i.e., the time when the shoreline practically reached its present position. In 1905 (p. 125) he suggested that the term be applied for the time elapsed since the shoreline at Oslo was situated approximately 8 m above its present position.

Feyling-Hanssen (1954 a, b; 1957) has taken up the study of the *Foraminifera* in Late Quaternary marine clays from an eco-stratigraphical point of view (Cp. Holtedahl, 1960, p. 387). Micropaleontological investigation of cores from a considerable number of borings in the Oslofjord area revealed distinct foraminiferal zonation through the cores. Certain assemblages were recognized, and recognized in the same succession, in most of the borings. These faunal changes presumably reflect changes in the marine environment during the sedimentation of the deposits. A general amelioration of the marine-climatic conditions from Arctic to Sub-Boreal occurred, and a regional isostatic land rise caused a shallowing of the water in every locality of the investigated area, to mention two factors only. Species which dominate the fauna under glacial conditions become less frequent, may even disappear, with raised water temperature, expelled by new species which become dominant. Shallow-water species generally appear in the upper parts of the cores and increase in frequency towards the top levels. A subdivision of the deposits based on the foraminiferal zonation established in this way is entirely ecologically conditioned and necessarily has only a limited regional applicability. Nearly all, if not all, the Foraminifera species found in the cores will appear to be represented also in marine faunas of the present-day. Probably none of them have become extinct during Late Quaternary time. Therefore a biostratigraphy based upon phylogenetic changes cannot be applied for these young sediments. – For the purpose of brevity the units of the Foraminifera zonation of the cores were simply called *zones*, and, again for the purpose of brevity, they were indicated by letters. Subdivisions of zones were termed *sub-zones*.

Zone A, the *Elphidium incertum clavatum zone*, is mainly represented outside (to the south of) and within the Ra ridge. *Elphidium incertum clavatum* occurs in abundance (60–100 %) and *Cassidulina crassa* is fairly frequent. The number of different species of Foraminifera per sample (dry weight 100 g) is between 5 and 20. Zone A has been subdivided into three subzones, A_{lower}, A_{middle}, and A_{upper}. The middle subzone, which, according to two radiocarbon datings, seems to be contemporaneous with the Ra formation, is characterized by frequent occurrence of *Nonion labradoricum* in addition to the above-mentioned species.

Zone B, the zone with *Virgulina loeblichi* and *Nonion labradoricum*, is still dominated by *Elphidum incertum clavatum* and *Cassidulina crassa*, but the number of different species is considerably greater than in the previous zone. Deposits with zone B-assemblages have their main distribution to the south of the Ås–Ski moraines in the Oslofjord area, thus occurring to the south as well as to the north of the Ra ridge.

Zone C, the zone with *Virgulina loeblichi* and *Cassidulina laevigata carinata* Silvestri, is found in deposits to the south of and in front of the moraines of the Aker substage, and is generally the oldest clay in and around the city of Oslo. Its fauna is similar to that of zone B, except that *Cassidulina laevigata carinata* is more common than *N. labradorium*.

Zone D, poor assemblages dominated by *Elphidium incertum clavatum* and *Cassidulina crassa* and with quite common occurrence of *Quinqueloculina stalkeri*, is found in front of, as well as north of, the moraines of the Aker substage. These sediments were presumably deposited during the final, rapid retreat of the ice margin, when large quantities of fresh and turbid melt-water gushed into the comparatively shallow and narrow northern parts of the Oslofjord of that time, and most probably considerably reduced the salinity of the fjord water. Up to the deposition of the zone D layers the hydrothermal conditions were Sub-Arctic. They seem to have prevailed into the older part of Boreal age.

Zone E, the *Elphidium incertum* zone, with *Elphidium incertum clavatum* and *Elphidium incertum incertum*, occurs both in the southern and in the northern Oslofjord district. It seems to be the oldest unit deposited in

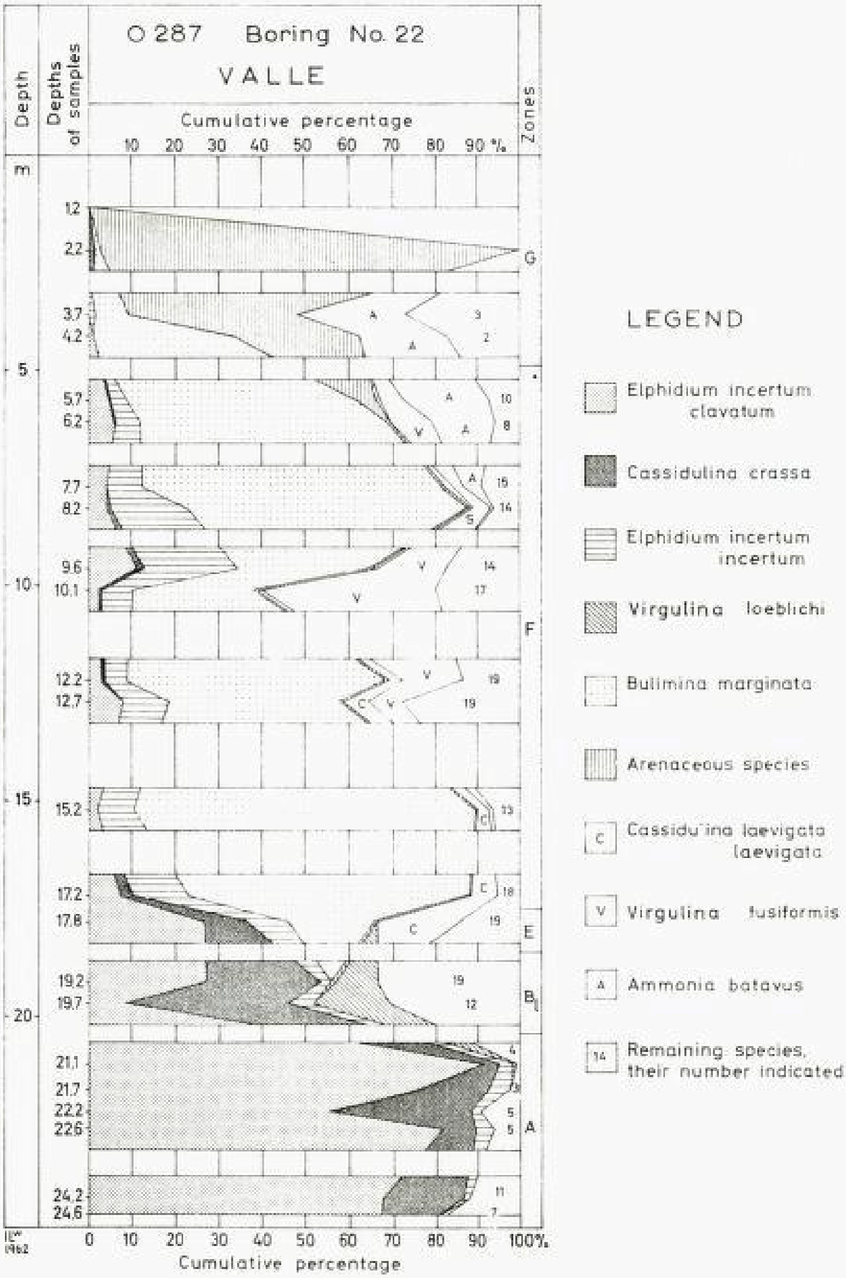

Figure 7. Foraminifera zonation of Late Quaternary clay deposits of a boring from the southern part of the Oslofjord area. Depths in metres.

temperate water. The number of different species has increased (25–30 per sample) and so has the number of specimens. The fauna has become Boreal with frequent occurrence of *Bulimina marginata* forma *aculeata* and *Cassidulina laevigata laevigata*. In some of the borings from the city of Oslo a layer with zone D-assemblage was observed within zone E.

The border between zone E and zone F is tentatively drawn; it should probably have been placed higher in the columns.

Zone F, the *Bulimina marginata* zone, is predominated by *Bulimina marginata* forma *aculeata*, *Elphidium incertum incertum* and *Nonion barleeanum* being frequently represented. Among other Boreal, and even Mediterranean Atlantic, species in this zone are mentioned *Amphicoryna scalaris, Angulogerina angulosa, Uvigerina peregrina, Nonionella turgida, Epistominella exigua, Höglundina elegans*. The sediments of this zone are supposed, for the main part, to have been deposited during Atlantic and Sub-Boreal time. Zone F- assemblages occur also in younger sediments, of Sub-Atlantic (Recent) age, but differ from the older F- assemblages by the frequent occurrence of *Nonion labradoricum* in them and in their very low content of *Elphidium incertum incertum*. A subdivision of zone F is natural, especially in cores from the southern part of the area: F_{lower}, characterized by frequent occurrence of *Cassidulina laevigata laevigata*, F_{middle}, with high percentage of *Virgulina fusiformis*, and F_{upper}, characterized by *Ammonia batavus* (= *Streblus batavus*) and *Hyalinea balthica* (= *Anomalina balthica*). These subunits probably (F_u certainly) represent certain depth zones during deposition of the zone F sediments.

Zone G, predominated by arenaceous shallow-water species, comprises sediments with more or less poor faunas. *Verneuilina media* or *Eggerella scabra* dominates, whereas *Nonion depressulus asterotuberculatus* and *Ammonia batavus*, sometimes also *Elphidium excavatum* occur quite commonly. When deposited in more or less stagnant water, zone G abounds in *Miliammina fusca*, and *Jadammina polystoma* may be frequent. Zone G represents Holocene shallow-water sediments probably deposited at depths less than 25 m. They are, as yet, found up to 55 m above present-day sea level in the Oslofjord area, and are in most instances contemporanous with parts of the zone F deposits.

Firn line

Liestøl (1960, p. 485) published a diagram illustrating the variation in the height of the firn line during the Holocene and latest part of the

Pleistocene epochs. The curve, which has been redrawn for the present chart, was constructed under consideration of, i. a., occurrence and disappearance of lateral moraines at certain heights and the relation between the height of the timberline and the height of the firn line (Cp. Holmsen, 1916).

Sammendrag.

Parallellisering av noen norske sen-kvartære inndelinger.

Det er konstruert et skjema omfattende de stratigrafiske resultater av noen norske undersøkelser innenfor kvartær-geologien. Utvalget er tilfeldig, men nyere undersøkelser er i noen grad tatt med til fortrengsel av eldre. Det er tatt med pollen-undersøkelser, strandforskyvning i senkvartær tid i nord og syd og likeså noen påviste transgressjoner. Videre har stadier i strandforskyvningen, basert på forekomst av marine mollusker i littoralsedimenter, i et par norske lokaliteter såvel som på Spitsbergen fått plass i skjemaet og dessuten leirsedimenter klassifisert ved sitt innhold av marine muslinger og foraminiferer. Substadier i innlandsisens avsmeltning, markert ved randavsetninger nord og syd i landet, har fått sine søyler i skjemaet, og endelig er det tegnet inn en kurve over variasjoner i firngrensens høyde i det vestlige Norge gjennom sen-kvartær tid.

Den velkjente *Blytt–Sernander's inndeling*, grunnet på myrundersøkelser, er, i noe modifisert form, å finne til venstre i skjemaet. Den antas å være kjent av kvartærgeologer over hele verden og kan gjøre tjeneste som en internasjonal standard som de mindre kjente norske inndelinger kan refereres til. Som en annen internasjonal standard er tatt med det *Danske pollen-analytiske sone-system* (Jessen, 1935, 1938), og som en tredje De Geer's sen-kvartære *geokronologi* basert på studier av varvig leire (De Geer, 1912). De Geer brukte betegnelsene *Sen-Glacial* og *Post-Glacial* på litt annen måte enn pollen-stratigrafene bruker dem idag. Pollen-stratigrafenes måte å bruke termene på er illustrert på venstre side av Blytt–Sernander-sekvensen i skjemaet. I samme søyle er inntegnet det *Post-Glaciale Varme Interval* eller *Post-Glacial Varmetid* (det samme som Flint og Deevey, 1957, kalte Postglacial Hypsithermal Interval), omfattende *Boreal*, *Atlantisk* og *Sub-Boreal* tid (sml. Gams og Nordhagen, 1923, p. 293; Firbas, 1954). Post-Glacial Varmetid i engere forstand omfatter bare Atlantisk og Sub-Boreal tid.

Til venstre i korellasjonsskjemaet er påført de sen-kvartære epoker *Pleistocene*, av hvilken bare seneste del er representert, og *Holocene*. I overensstemmelse med vanlig bruk (Woldstedt, 1954, p. 2) faller grensen mellom de to epoker sammen med grensen mellom *Yngre Dryas* og *Pre-Boreal*, hvilket er det samme som grensen mellom Sen- og Post-Glacial slik pollen-stratigrafene legger den.

De forskjellige sonegrenser i skjemaet er såvidt mulig henført til en absolutt tidsskala ved hjelp av tilgjengelige radiocarbon dateringer (bl. a. Gross, 1958; Radiocarbon Supplement, vol. 1, 1959, vol. 2, 1960; Radiocarbon, vol. 3, 1961, vol. 4, 1962). Med hensyn til pollensonegrensene II/III, I/II, Ib/Ic og Ia/Ib refereres spesielt til Tauber (1960a og b). Tidsskalaen ril venstre i skjemaet angir tiden i år før nutid (1950) mens tidsskalaen til høyre gir årstall før og efter Kristi fødsel.

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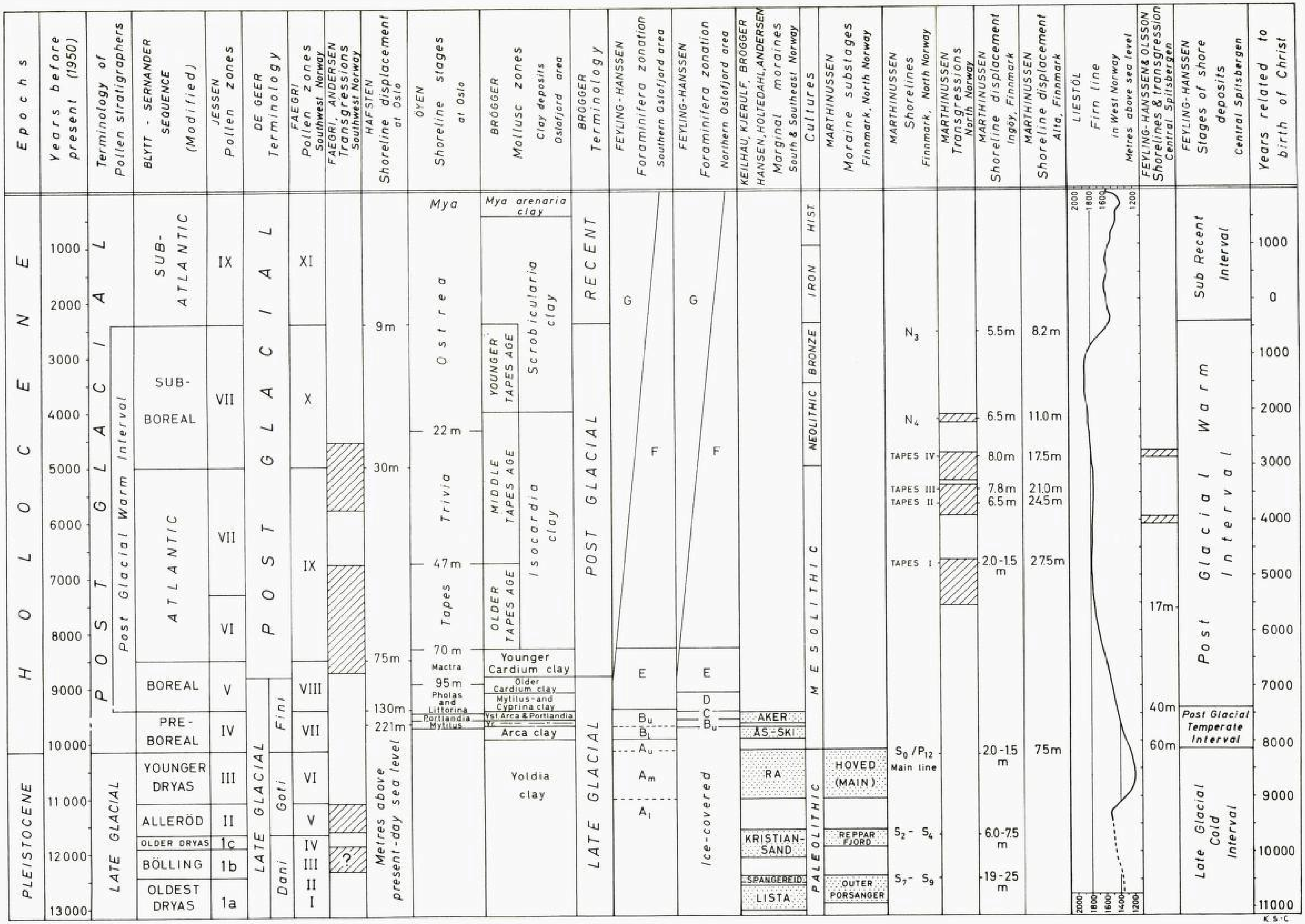

Plate 1. A Late Quaternary correlation chart for Norway.

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