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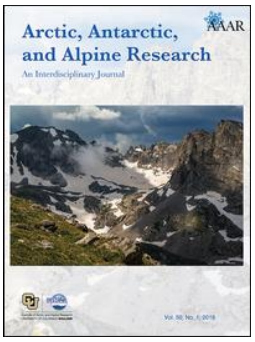

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HUMAN INFLUENCE ON NATURAL ARCTIC VEGETATION IN THE 17TH CENTURY AND CLIMATIC CHANGE SINCE A.D. 1600 IN NORTHWEST SPITSBERGEN: A PALEOBOTANICAL STUDY

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ABSTRACT

Paleobotany is used to study the human influence on vegetation in the first half of the 17th century around Smeerenburg, a temporary Dutch whaling settlement on Amsterdam Island in northwest Spitsbergen. The local vegetation succession recorded in a settlement diagram indicates that the nutrient level of the soil increased strongly during the settlement period and decreased only slowly after the departure of the whalers. Climatic change since A.D. 1600 is reconstructed with palynological methods. The core from the settlement contained in layers representing the settlement period a great number of pollen types alien to Spitsbergen, evidently brought there by the Dutch whalers. In bird-cliff sediment cores collected 4 km from Smeerenburg these types were used to trace the settlement period. In a peat bog core collected about 100 km south of Smeerenburg the settlement period was traced by a radiocarbon date. Additional chronological correlation was established by means of lithological characteristics. At the bird cliff and in the peat bog no changes in local vegetation type were recorded during the last few hundred years. However, concordant trends observed in the pollen curves of the concentration diagrams were, by means of a simple calculation, rendered into separate curves for each diagram, defined as common-trend curves. The common-trend curves are interpreted in terms of climatic change. The reconstructed climate is as follows: a general deterioration during the first half of the 17th century, only interrupted by a short and passing amelioration. The results are in accord with climatic reconstructions in literature for northwest Spitsbergen based on historical data and for Camp Century (Greenland) based on an ice core. The diagrams indicate the former presence of two taxa not yet known from Spitsbergen: *Myriophyllum spicatum* and *Parnassia*.

INTRODUCTION

During the years 1980 to 1982, palynological studies were carried out on materials from Amsterdam Island and Brøggerhalvøya, northwest Spitsbergen, as part of the so-called Smeerenburg project of the Arctic Centre, Rijksuniversiteit, Groningen, The Netherlands. The aim of this multidisciplinary project is to investigate and reconstruct the living and working conditions of the 17th-century Dutch whalers in Spitsbergen.

The Dutch whalers hunted especially the Greenland whale. The main hunting area was situated in the northwestern corner of Spitsbergen in the Smeerenburg Fjord, a bay separated from the northern Atlantic by Amsterdam Island and Danish Island. Between about 1615 and 1650 a small whaling station called Smeerenburg (Blubber Town) developed along the fiord on the sandy beach of Amsterdam Island. The ideal feeding area for the Greenland whale was determined by the proximity of drift ice and the zone of confluence of cold and warm waters from the eastern and western Spitsbergen currents (the convergence zone). Changes in the position of drift ice and sea currents strongly affected the whaling industry, because it influenced both the position of the feeding areas of the Greenland whales and the length of the working season of the whalers. A close relationship between the activities of the 17th-century Dutch whalers in Spitsbergen and climatic changes can therefore be expected. Possible changes in climate during the 17th century are reconstructed here by means of paleobotany and the results are compared with historically recorded changes in climate. Deposits formed during the last few centuries were collected on Amsterdam Island and on Brøggerhalvøya, about 100 km to the south. The methods included the study of macrofossils and pollen analysis, both of cores and of surface samples.

SITES OF INVESTIGATION

Figures 1 and 2 show the location of the five cores and of the surface samples.

Smeerenburg

A core was collected in the Smeerenburg settlement, only 15 m from the remains of a house, about 2 m from a fresh-water lagoon, at about 75 m from the sea and a few meters above sea level. Undisturbed sediment of thin horizontal moss and sand layers underlies and overlies a foul-smelling zone containing pieces of brick, wood, and coal between 15 and 18 cm.

Søre Salatberget

Three cores were collected from a small patch of vegetation on the bird cliff "Søre Salatberget" 4 km west of Smeerenburg, about 40 m above sea level. The vegetation layer was removed from the cores in the field. The material is compact and has clear strata, mainly of plant remains, including some sand and small stones, fragments of bones and feathers of birds, fish-bones, and fragments of shells and crustaceans.

Stuphallet

A core was collected from a peat bog below the bird cliffs of Stuphallet on Brøggerhalvøya, about 100 km south of Smeerenburg, and 7 km northwest of the world's northernmost human settlement, Ny Ålesund, about 30 m above sea level. The core was taken from the frozen side of a narrow, deeply incised small stream in the middle of the bog. The length of the core in the field was 85 cm, but it shrank to 75 cm due to melting of ice layers below 30 cm and especially below 60 cm. The lithology is as follows:

0–3 cm: living mosses
3–16.75 cm: thin layers of compact moss material, no sand
16.75–17.25 cm: black remains of *Saxifraga oppositifolia*
17.25–22.5 cm: compact, decomposed mosses, silty
22.5–46 cm: loose mosses, obscurely layered, some sand
46–75 cm: loosely curled mosses, no apparent stratification, some sand; below 60 cm there are irregular ice layers, and at 44–48 cm there is a hollow with a plug of fresh mosses (not sampled).

In the field at least 30 cm of pure ice was observed below the core. See Appendix for a more complete description of the sites and the vegetation of the coring and the surface-sample sites.

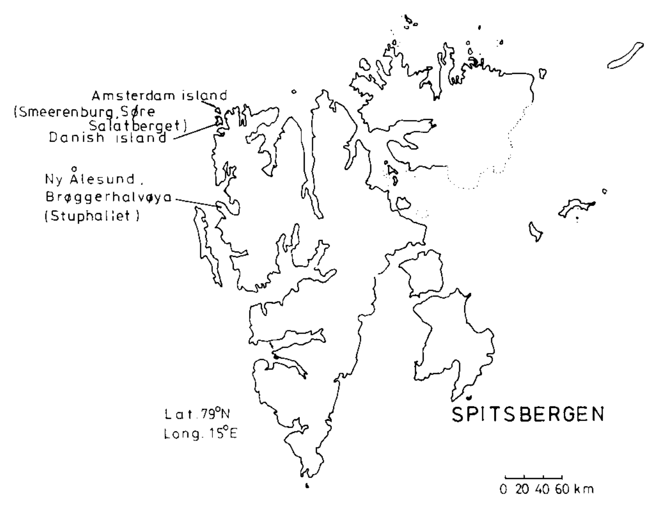

FIGURE 1. Map of Spitsbergen indicating coring localities (names of coring sites in parentheses).

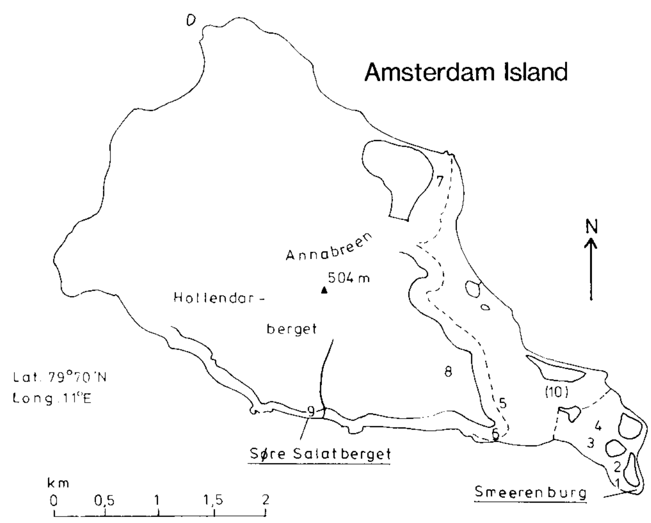

FIGURE 2. Map of Amsterdam Island indicating coring localities (underlined) and surface-sample localities (numbers 1–10).

METHODS AND PRESENTATION OF RESULTS

Laboratory Methods

The Smeerenburg core was subdivided into 19 sections. Two small samples of organic material were taken from each section, one for pollen analysis and a parallel sample for loss-on-ignition determination. The remaining material was used entirely for the analysis of macrofossils.

The samples from the other cores all have a length of 0.5 cm. Consequently, Søre Salatberget core C and the upper 23 cm of the Stuphallet core were sampled continuously, but for the rest there are gaps between the samples.

A constant volume was sampled in Søre Salatberget cores A and B by pushing the sediment with a spatula into a small sampler of a known volume. Dry weight was measured for samples of Søre Salatberget core C and the Stuphallet core. Pollen concentrations were determined by the addition of tablets containing a known number of spores of *Lycopodium clavatum* (Stockmarr, 1971). Unfortunately, volume and dry weight were not measured simultaneously for all samples of the five cores. Treatment methods, more fully described by Faegri and Iversen (1975), are mentioned here briefly: (1) addition of a *Lycopodium* tablet to each sample and gentle heating in HCl 30%; (2) heating for 5 min in KOH 10%; (3) sieving of the samples in one of two ways (for Søre Salatberget cores A and B and the Smeerenburg core the material was sieved over a 0.25-mm mesh screen. Pollen and spores in the samples of Søre Salatberget core C and of the Stuphallet core were concentrated by sieving the material over a 0.12-mm mesh screen, followed by heating at 90°C for 10 min in KOH 10%); (4) cold overnight treating with HF 30%; (5) acetolysis.

Loss-on-ignition was determined for Søre Salatberget core C and for the Stuphallet core. Radiocarbon dates (one level in Søre Salatberget core B and six levels in the Stuphallet core) were provided by Prof. Dr. W. G. Mook of the Isotope Physics Laboratory, Groningen, The Netherlands. The actual number of pollen and spores counted was not fixed a priori, but about six to ten morphological types was considered reasonable, depending on the core. No more than three slides were counted for any of the samples. In the Søre Salatberget cores the so-called black chips, supposed to originate from the cooking of whale blubber, were also counted. These black chips constitute pitch black particles, sometimes with bluish edges (those with brown edges were excluded), with shapes reminiscent of broken glass, with straight or curved sides and sharp angles, but never with granulate margins.

The surface samples were treated in the same manner as the cores, but no *Lycopodium* tablets were added.

All pollen grains and spores of vascular plants and *Sphagnum* were identified to the lowest possible taxonomic level. Verbeek-Reuvers (1977a) was used for the identification of Saxifragaceae pollen.

Presentation of Results

The results are presented here as concentration diagrams for all sites and a relative diagram for part of the macrofossil analysis of the Smeerenburg core. Pollen and spore types have been grouped into three categories:

Local-regional component. Pollen and spores that are presumed to be derived from plants growing on Spitsbergen.

Long-distance component. Pollen and spores originating in areas outside Spitsbergen; usually grains of relatively small size and often somewhat corroded.

"Pollution" component. Pollen and spores brought to Spitsbergen unintentionally by the 17th-century Dutch whalers. These grains are of normal size and well preserved, easily distinguishable from those of the long-distance component. This "pollution" component was mainly found in the Smeerenburg core and in Søre Salatberget core C. The black chips are included in this component, although they do not strictly fall within the definition. The reason is the close correlation of the black chips with the remaining part of the "pollution" component in Søre Salatberget core C.

Zonation

Zones based on lithology and biostratigraphy were established for ease in reference. In the Stuphallet diagram four zones (A-D) have the character of both beds and pollen assemblage zones; an additional zone E is characterized solely by its lithology. In the Smeerenburg diagram a zonation (zones A-D) based on micro- and macrofossils was established. In the comparative diagram (Figure 10) a lithological zonation is used to facilitate the interpretation in terms of climate.

RESULTS

Surface Samples (Figure 3)

Local Pollen Deposition

Nearly all plant taxa recorded around the sampling sites are represented in the diagram by corresponding pollen types. The quantitative order in the deposition is as follows: Cruciferae pollen show very high values; *Saxifraga granulata* type and Gramineae have intermediate values; all other types have low to very low values. A number of taxa present at the sampling sites were never found as pollen in the samples, viz. *Stellaria humifusa, Sagina intermedia, Silene acaulis,* and (partly) *Saxifraga nivalis.* Despite the low pollen-deposition rate, interesting relationships with vegetation patterns can be established (see Appendix).

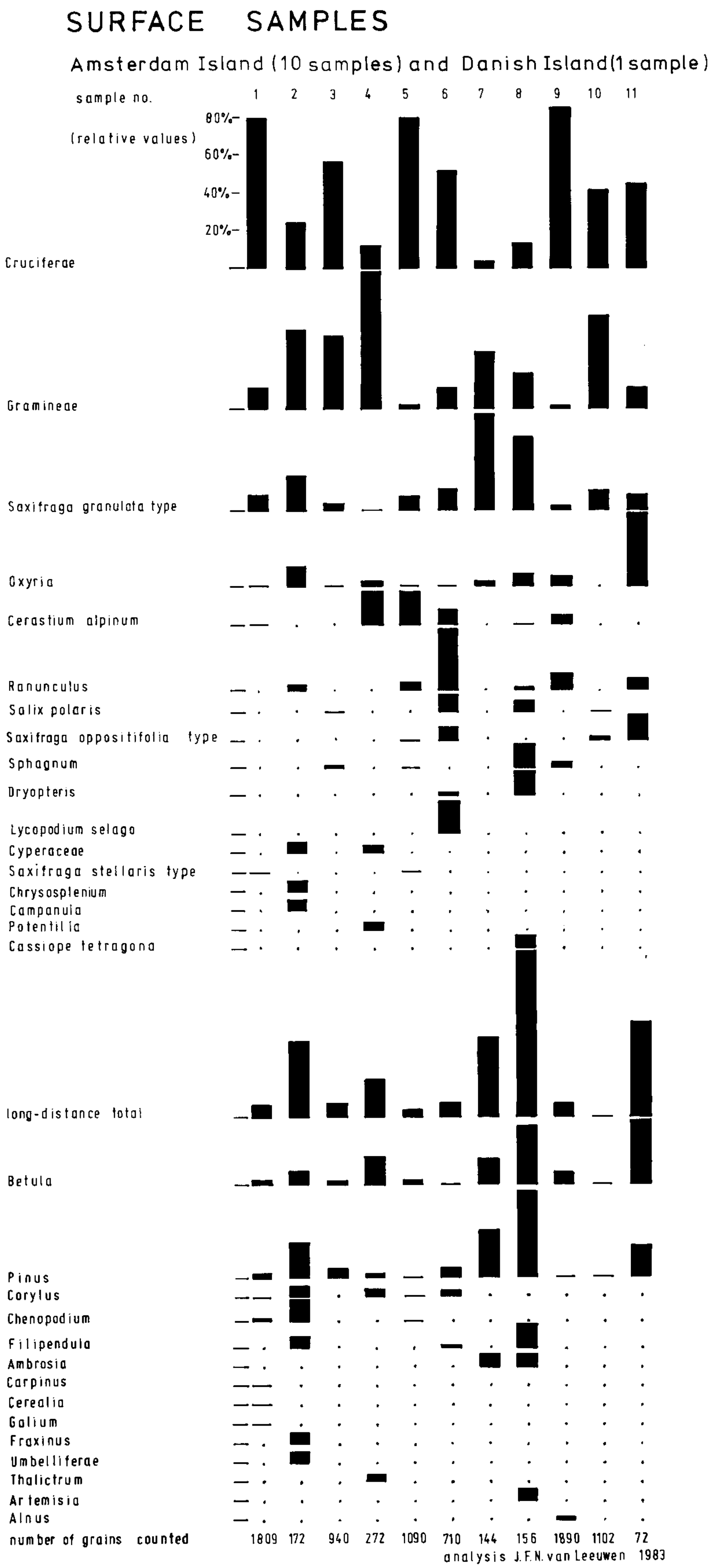

FIGURE 3. Surface-sample diagram. For description of sites and vegetation, see Figure 2 and Appendix.

Regional Pollen Deposition

Pollen and spore types of taxa that grow on Spitsbergen but not within a considerable distance of the sampling sites are found occasionally, usually as one or a few grains. These types do not reflect the vegetation of Amsterdam Island, despite the great diversity in this group.

Long-distance Pollen Deposition

The deposition of pollen and spores from plants growing outside Spitsbergen is very low and only exceeds 10% if the vascular-plant vegetation of the sampling site is exceedingly sparse.

These observations are confirmed by other surface-sample studies in the High Arctic (e.g., Kalugina et al. [1981] on October Revolution Island, U.S.S.R., and Środoń [1960] in the Hornsund area, south Spitsbergen).

SMEERENBURG: PAST VEGETATION AND ENVIRONMENT (FIGURE 4)

The macrofossil diagram of Smeerenburg reveals much about changes in local vegetation and environment, especially when the ecology of the taxa and the lithology of the sediment are taken into consideration.

The large amount of sand in the sediment and the irregular spacing of the organic layers indicate that the vegetation was repeatedly being buried and that the accumulation rate of the sediment may not have been constant. The following ecological succession took place:

Zone A

The scarcity of plant remains in the sand deposited before the period of settlement at Smeerenburg indicates a very sparse vegetation, possibly caused by a rapid deposition of sand.

Zone B

These layers represent the settlement period. A dense grass mat of *Phippsia* replaced the very open moss vegetation of *Drepanocladus* in zone A. This is clearly due to strong enrichment of the soil by whaling activities. The "pollution" component in the pollen diagram comprises nearly exclusively pollen types from taxa that definitely could not have grown on Spitsbergen because of the high arctic climate (exceptions: Compositae liguliflorae, Caryophyllaceae). The relatively high values of Cerealia and *Erica* indicate that these pollen types were probably unintentionally carried to Smeerenburg by the whalers in shipments of straw and brooms. Brooms were actually found in the archaeological excavations of Smeerenburg (Hacquebord, 1984).

Zone C

A local succession from *Phippsia* to *Saxifraga* and finally to *Cochlearia* is recorded after the abandonment of the settlement. The ecology of the taxa involved suggests that the soil nutrient level gradually decreased. In section 10 the amount of vascular plants decreases temporarily and *Polytrichum norvegicum* reaches a maximum, resulting in a period with extensive deposition of sand.

Zone D

A dense moss cover of *Drepanocladus* reestablished, suggesting a low nutrient level of the substrate. The density of the moss cover and the appearance of taxa that grow today on moist (*Pohlia albicans*) or wet (*Calliergon trifarium*) soils indicate that the soil had become much moister. Shell fragments in the upper three sections suggest recent flooding. The absence of salt-resistant taxa in the vegetation indicates that the source of this flooding is the neighboring fresh-water lagoon.

STUPHALLET: PAST VEGETATION (FIGURE 5)

The peat core from Stuphallet consists almost exclusively of mosses. The scarcity of vascular plants is confirmed in the diagram by the rather low concentrations of most pollen types. Only the curves for Cruciferae and *Saxifraga granulata* type in zones D and E and the curve for *Saxifraga oppositifolia* type at 17 cm show the irregular behavior and high concentrations characteristic of local pollen deposition; these taxa were probably growing at the actual site. The almost constant presence of the first eleven types listed in the diagram (from Cruciferae to *Oxyria*) indicates, however, that the corresponding taxa were growing nearby. The deposition of these types can be considered to be extralocal (sensu Janssen, 1973). The observed differences between the zones of these types must therefore be interpreted as reflecting changes in the distance between the coring site and the pollen sources. The fluctuations in the pollen values may thus not record major changes in vegetation type, but at the most only changes in vegetation pattern.

Dryopteris and *Sphagnum* spores are perhaps part of the long-distance deposition. Pollen of *Calluna* has not been found before on Spitsbergen. The finding of a tetrad at three different levels suggests that *Calluna* plants might have been present on Brøggerhalvøya; this needs confirmation. *Myriophyllum spicatum* occurs as one grain at 62 cm. Zelikson (1971) found two grains of *Myriophyllum* at 46 cm and one at 75 cm, dated ca. 2000 BP and 2250 BP, in a peat bog of 170 cm near the Van Meijen Fjord, Spitsbergen. These records are interpreted here as recording local or extralocal occurrence of the species, as long-distance dispersal of this type seems improbable. *Myriophyllum spicatum* is a plant of open water. The former presence of open water at the Stuphallet site is also indicated by the field observation of at least 30 cm of pure ice below the peat.

SØRE SALATBERGET: PAST VEGETATION (FIGURES 6, 7, 8)

The vegetation at Søre Salatberget did not change during the period covered by the diagrams. This can be concluded from the relatively constant values of the pollen and spore types in the local-regional component of the diagrams. The curves of the five dominant types (Cruciferae, Gramineae, *Cerastium alpinum, Ranun-*

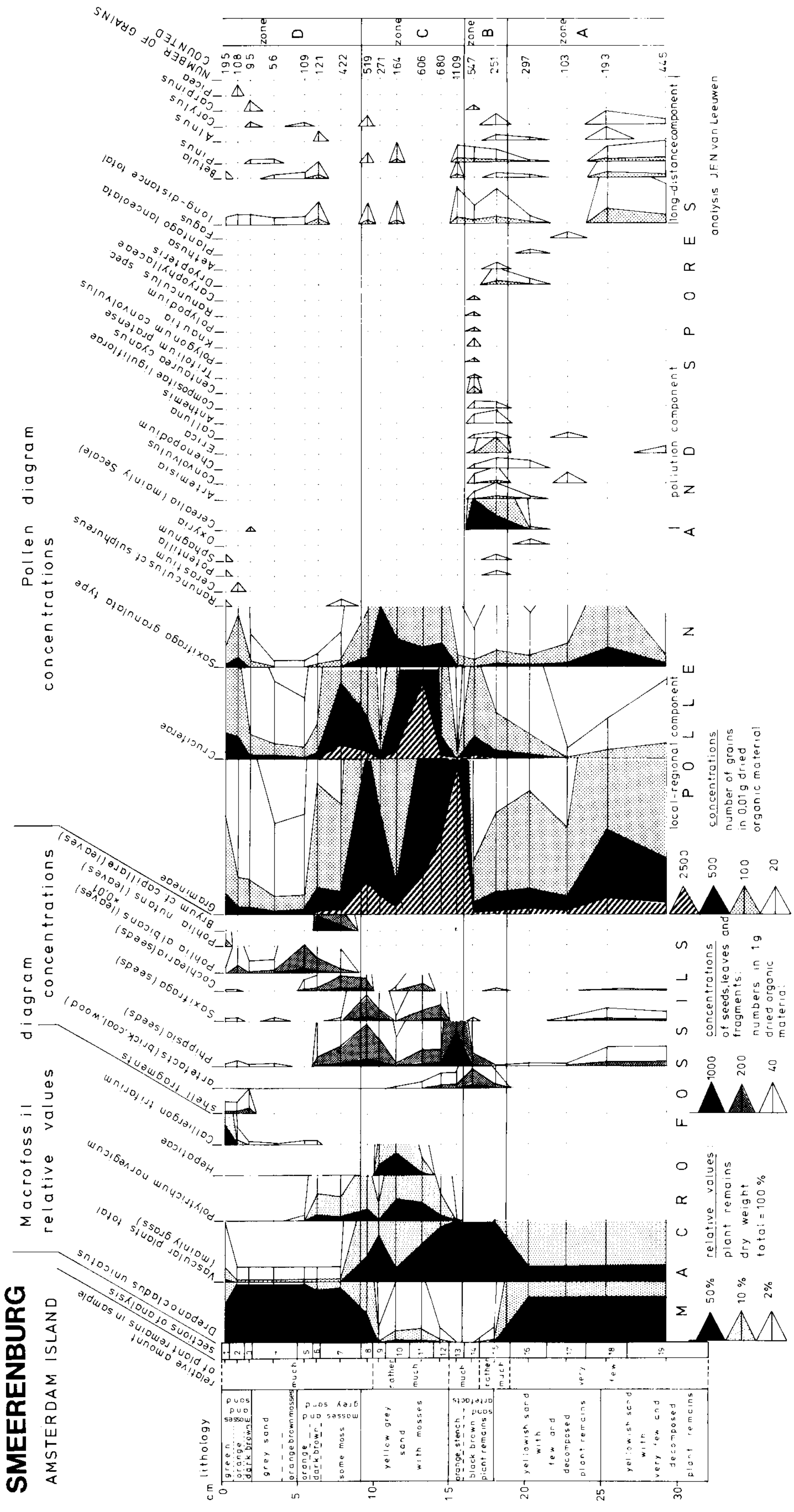

FIGURE 4. Smeerenburg diagram.

culus, Saxifraga granulata type) show the typically irregular fluctuations and high concentrations associated with local-pollen deposition. The other types within this component are mainly found in Søre Salatberget core C, because of the greater number of grains counted. Seven of these types are probably of local origin, or derived from plants on the slopes above the site: *Oxyria, Papaver radicatum, Salix polaris, Saxifraga stellaris* type, *Polygonum viviparum, Chrysosplenium* (2 grains at 19.5 cm), *Parnassia*. The plant *Papaver dahlianum* was not observed on Amsterdam Island, but it can easily have been overlooked, as the suitable habitats have not been studied sufficiently. Its high pollen concentration at 7 cm should be noted. *Parnassia* pollen (4 grains at 17 cm) is also of interest. The identification of this very characteristic pollen type is quite reliable. The grains belong to the microreticulate type (Verbeek-Reuvers, 1977b). The plant is not known from Spitsbergen and the pollen type has not been found there before.

The other types within the local-regional component could very well all be part of the regional-pollen deposition. *Dryopteris* and *Sphagnum* spores, though classified in the local-regional component, may perhaps in fact be part of the long-distance deposition. In the five levels analyzed for macrofossils in Søre Salatberget core A (0, 8, 14, 15, and 27 cm; not further discussed here), leaves of *Sphagnum* were found. However, the plants were probably sterile, as the consistently low concentrations of the spores suggest that the spore deposition was not of local origin.

Stuphallet: Chronology (Figure 9)

Zones B, C, D, and E

The peat in zones B, C, D, and E is distinctly layered. This, and the four radiocarbon dates in chronological sequence within these zones indicate that the sediments have not been mixed. However, the lithology suggests a gap in the record between zones D and E; at this level a thin black layer separates two different types of peat. This is confirmed by the radiocarbon dates in zones D and E being about 1000 yr apart. There are no indications that any additional gaps occur.

The transition zone C/D is very marked; a change in accumulation rate at this level therefore seems probable. A possible accumulation curve is indicated in Figure 9 by a dotted line. This results in the following possible dates for the transitions of the zones:

Base of zone E: ca. 320 BP
Top of zone D: ca. 1150 BP
Transition zone C/D: ca. 1560 BP
Transition zone B/C: ca. 1640 BP
Base of zone B: ca. 1900 BP

Zone A

The anomalously young radiocarbon date in the top of zone A compared with those in zones B, C, and D can be explained in two ways. First, contamination with fresh material from the plug of fresh mosses at 44 to 48 cm may have occurred, despite the extreme care taken to prevent this. Second, transportation of fossil material by the small stream to the coring site may have occurred. This is probable, as there are additional indications that the peat of zone A is heavily mixed and redeposited: the irregular structure of the peat, the absence of layering, the radiocarbon date at the base of this zone being younger than the radiocarbon date in zone B. The time of redeposition must be younger than the redeposited material itself, and can therefore be placed in the time gap between zones D and E (ca. 1150 to ca. 320 BP). The existence of a time gap in itself indicates circumstances not favorable for peat accumulation. Redeposition of peaty material by the small stream below already formed sediments without disturbance of these sediments seems very well possible when we observe the actual course of the stream in the field. The meanders at the base of the 1-m-deep incised stream deviate horizontally up to more than 1 m from the course at the surface; disconnected peat lumps will freeze easily in the arctic winter onto the sides of the incision.

Chronological correlation of the Stuphallet diagram with the Søre Salatberget diagrams is discussed below.

Søre Salatberget: Chronology and Correlation

The radiocarbon date in Søre Salatberget diagram B might be a few hundred years too old, because an unknown part of the carbon in the sediment has a marine origin (see, e.g., Donner and Jungner, 1979, and Tauber, 1979).

The "pollution" component in Søre Salatberget diagram C is also present in the Smeerenburg diagram and provides a means of time correlation. The period of greatest activity in the Smeerenburg settlement was approximately A.D. 1615 to 1650 (Hacquebord, 1983), so the levels where the "pollution" component or black chips occur must be of similar age. It is possible that sea birds brought the "pollution" component to the bird cliff where the cores were taken. It is known from historical sources that birds were present in great quantities around the settlement, defecating, screaming, and eating whale blubber.

The radiocarbon date in zone E of the Stuphallet diagram (290 ± 40 BP) (Figure 5) corresponds to a historical calendar date of A.D. 1635, with a lower limit (1490–) 1620 and an upper limit 1645 (Stuiver, 1982). This date is similar to the date of the levels with the "pollution" component in the Søre Salatberget diagrams (Figures 6, 7, 8). Six pollen types within the long-distance component of the Stuphallet diagram between 16 and 11.5 cm can now possibly be classified as belonging to the "pollution" component, namely *Urtica urens*, Cerealia, *Plantago lanceolata, Oenanthe, Fagus,* and Compositae tubuliflorae.

We have seen that any vegetation succession that occurred at Søre Salatberget is not reflected in the local and regional assemblages. Time correlation on basis of changes in the pollen assemblages is therefore not pos-

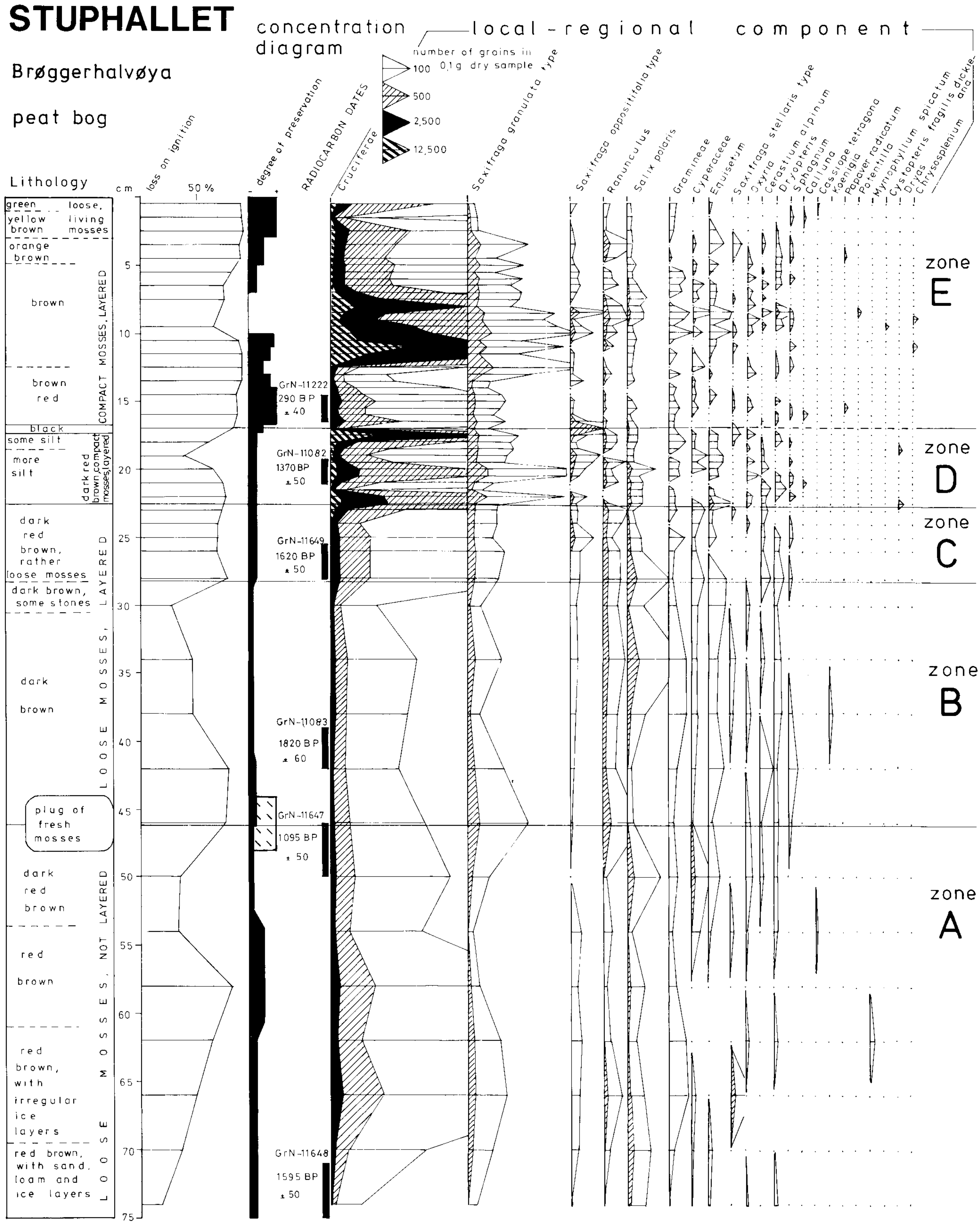

FIGURE 5. Stuphallet diagram.

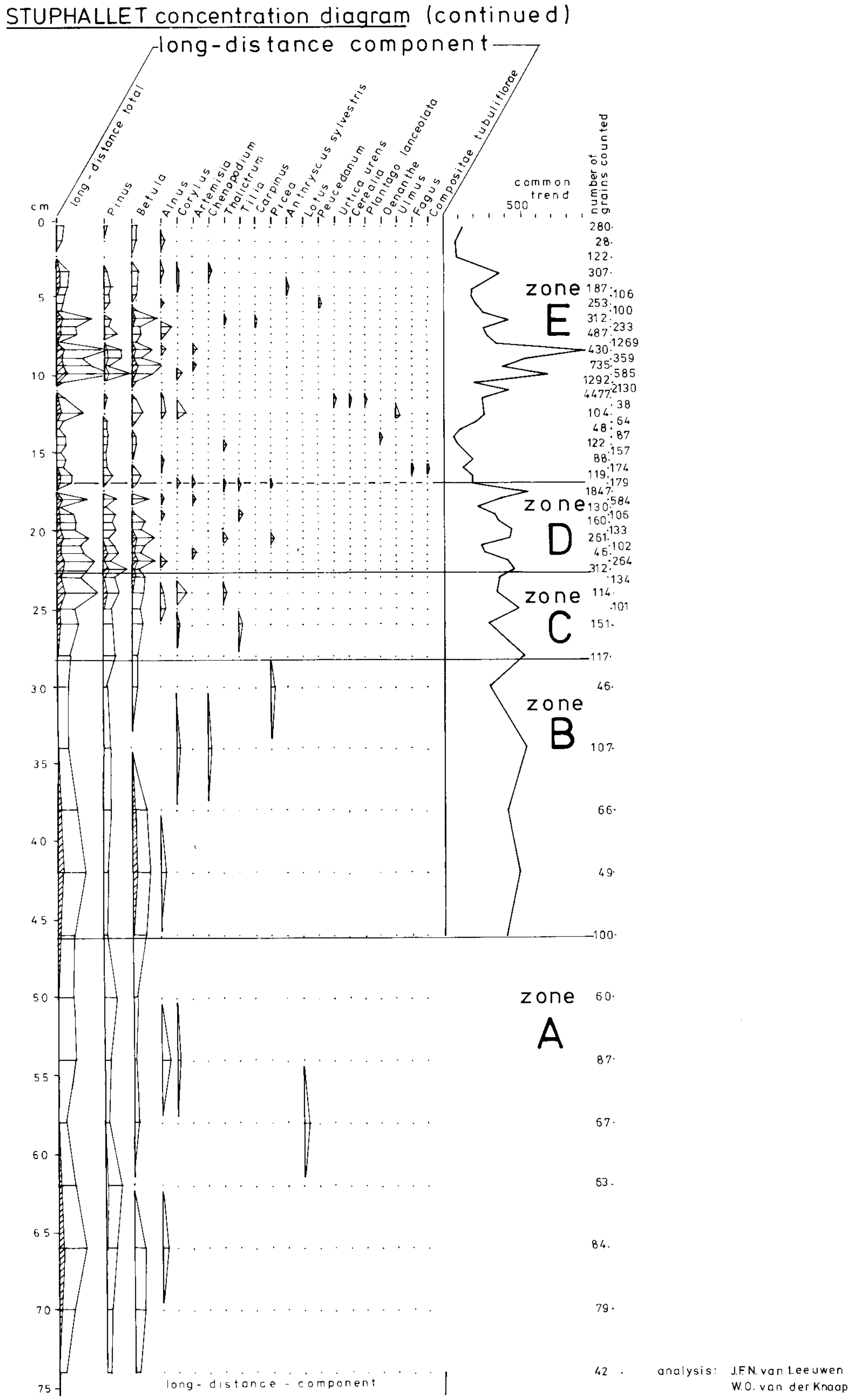

FIGURE 5 (cont.).

sible, despite the fact that these cores were taken within one small patch of vegetation. Instead, correlation of the cores is possible by delimiting "pollution" horizons as described before, and using lithological characteristics, notably the degree of preservation. In this way, three synchronous levels are established.

It will be shown later that the degree of preservation is presumed to be connected with regional climatic change. On this basis the Stuphallet diagram can also be correlated with the Søre Salatberget diagrams.

The synchronous levels are shown as the transitions between zones 1–4 in the comparative diagram (Figure 10), in which only the so-called "common-trend curves" (to be discussed later in this paper) and the black chips are reproduced. The "pollution" component indicates that zone 2 corresponds with the settlement period. The implication is that the sedimentation rate at Søre Salatberget has not been constant. It has been greatest in zone 2 and sedimentation stopped altogether in or at the top of zone 4 (cores A and C) or in zone 3 (core B). As the vegetation layer has been removed from the cores in the field, the upper spectra need not be synchronous. It seems that the present-day bird-cliff vegetation at Søre Salatberget does not cause peat accumulation any more.

Stuphallet and Søre Salatberget: Environment

Stuphallet

No interpretation in terms of environmental parameters will be given for zone A of the Stuphallet diagram (Figure 5), as the material is presumed to be redeposited.

The peat in zone C is more compact than in zone B. This suggests a shift in local conditions, namely a decrease in water supply of the vegetation. The transition zone

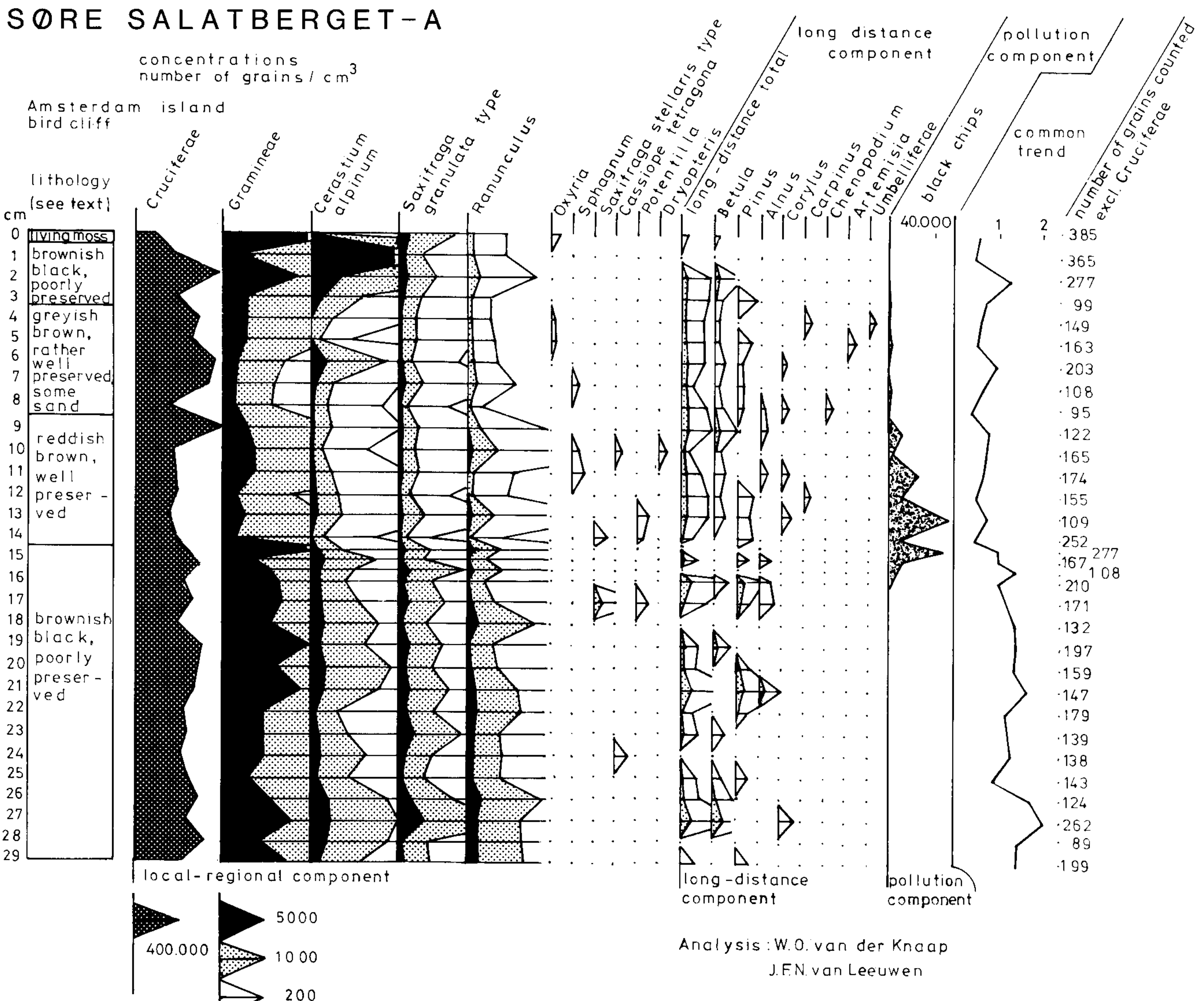

FIGURE 6. Søre Salatberget diagram A.

C/D is very marked, as the peat in zone D is much more compact and silty. This points to a strong decrease of water supply. The high concentrations of Cruciferae pollen in zone D support this view, as a dense growth of Cruciferae (mainly *Draba* species) on peat is nowadays only seen in relatively dry conditions. The gap between zones D and E might be caused by a further drying of the surface, eventually preventing peat growth. A further indication for this is the presence of a black layer at the transition zone D/E, formed by the remains of *Saxifraga oppositifolia,* a species that grows today on drier soils.

A detailed interpretation of zone E is given below.

Establishment of Common-trend Curves

In the Søre Salatberget diagrams (Figures 6, 7, 8), the curves of the five dominant pollen types mostly follow similar trends. For example, in Søre Salatberget diagram C the curves have relatively low values in the middle part and higher values in the upper and lower parts. A curve depicting common trends can now be established, in an attempt to portray the trends in the individual pollen types in a more easily available form for interpretation in terms of environmental parameters.

Calculation of common-trend values is based on the following criteria:

(1) The five dominant pollen types (Cruciferae, Gramineae, *Saxifraga granulata* type, *Ranunculus, Cerastium alpinum*) are only used.

(2) Concentration values are divided by the mean concentration for particular pollen types in separate diagrams, thereby ensuring that each pollen type contributes equally to the common-trend curve.

(3) A few extremely high concentration values, that are not synchronous between the diagrams, are excluded from the calculation. The excluded extremes are not characteristic for the common trends observed in the other curves; yet extremely high concentration values, if included, dominate the common-trend values. Excluded are the following: diagram A Gramineae, 0 and 14.5 cm; diagram B *Saxifraga granulata* type, 8 cm, *Cerastium alpinum,* 11 cm; diagram C *Ranunculus,* 0.5 cm, Gramineae, 4.5 cm, *Saxifraga granulata* type, 17.5 cm.

(4) An average value for the five types is calculated for every level and plotted in a curve, here defined as the common-trend curve.

In the Stuphallet diagram, some common trend can also be observed. Because the concentration values of

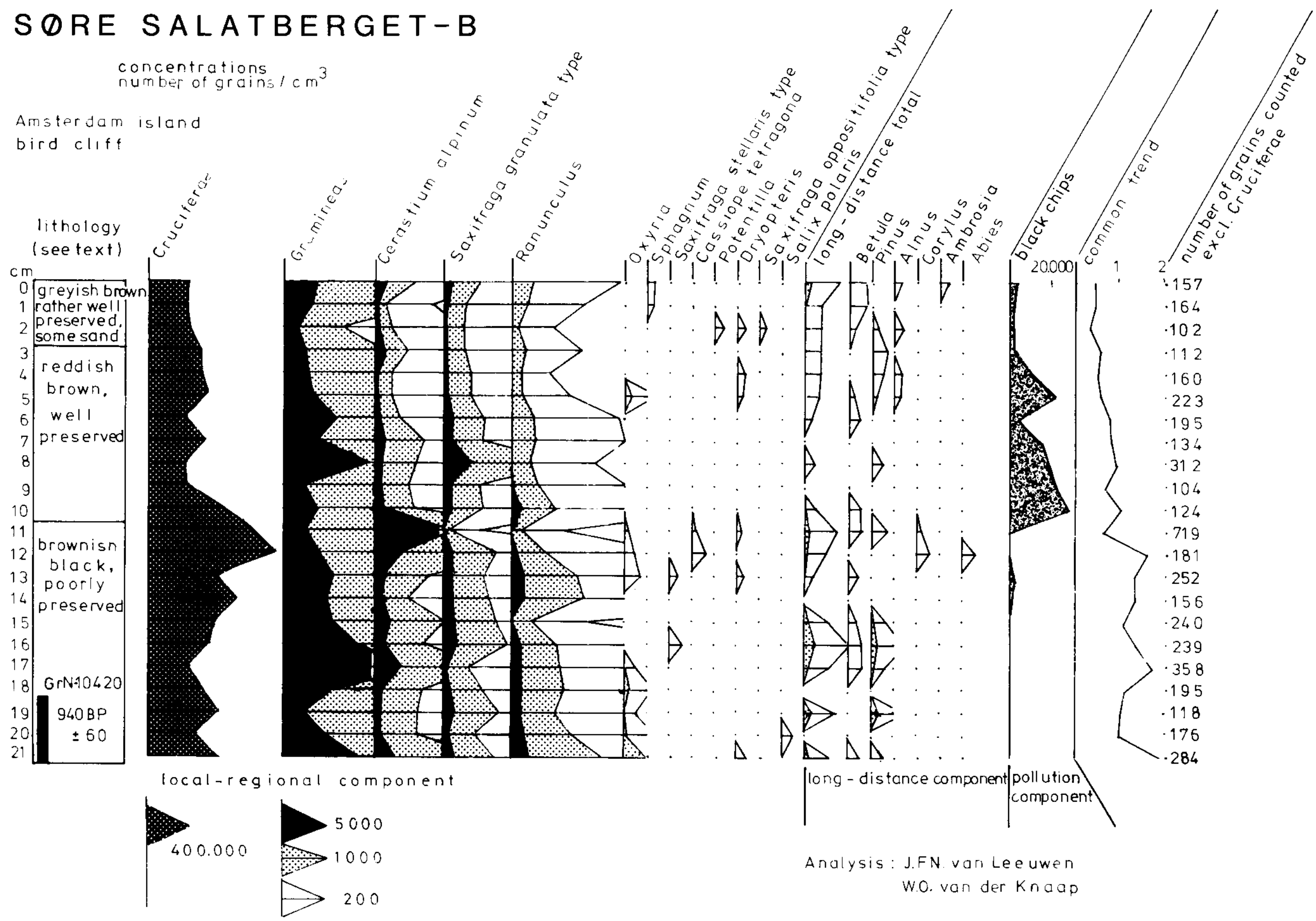

FIGURE 7. Søre Salatberget diagram B.

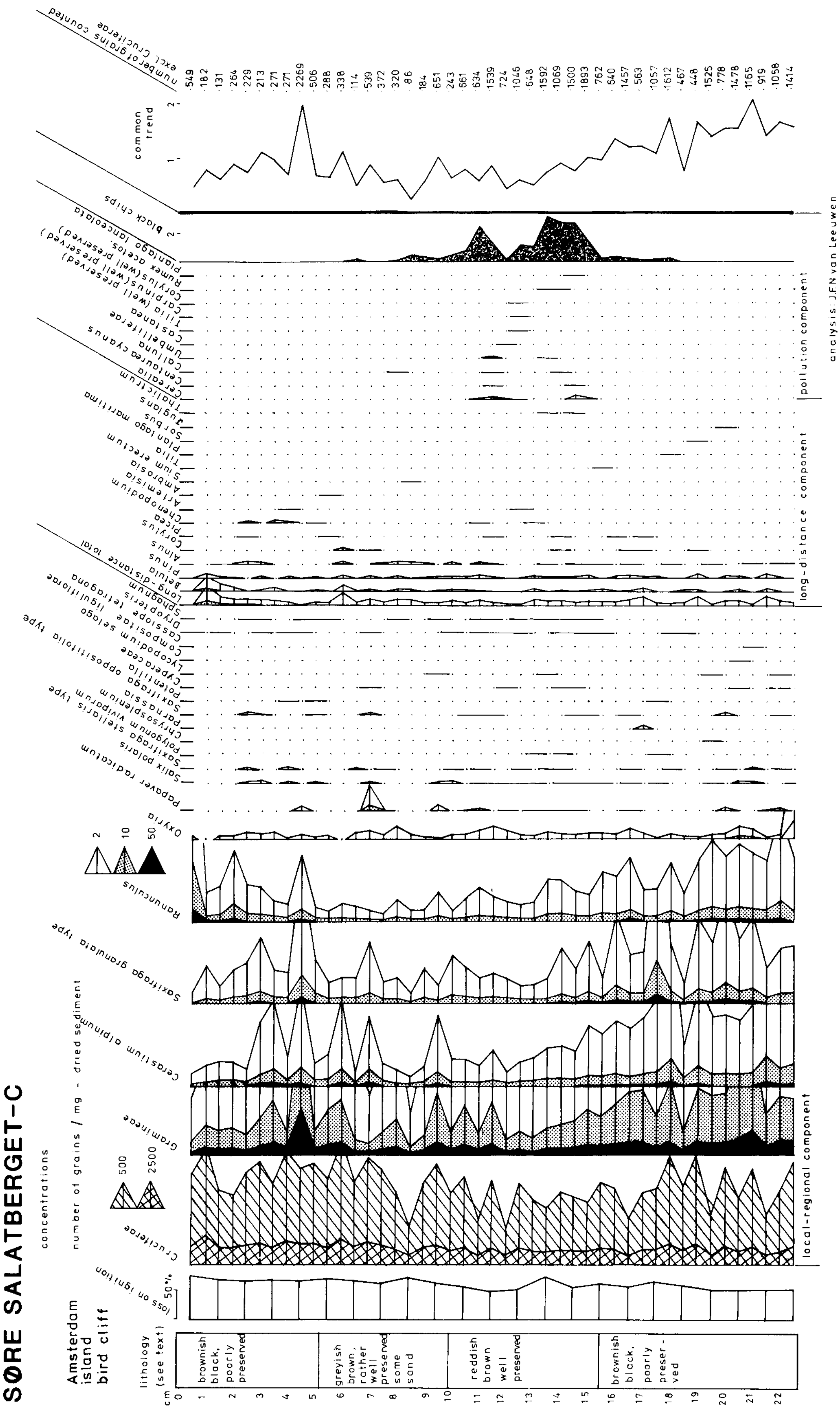

FIGURE 8. Søre Salatberget diagram C.

most pollen types are rather low, a different procedure has been followed here:

(1) the calculation is restricted to zones B to E;

(2) the influence of the dominant pollen types Cruciferae and *Saxifraga granulata* type is reduced by dividing by a fixed number, so that a mean concentration of 25 grains/mg, similar to that of many other types, is reached;

(3) the high concentration of *Saxifraga oppositifolia* type at 17 cm is replaced by the mean value for 16.5 and 17.5 cm;

(4) the total concentration values of all types are plotted at every level, resulting in a curve, defined here as the common-trend curve.

In the comparative diagram (Figure 10), the common-trend curves are smoothed by plotting the mean values of every two subsequent common-trend values (a running mean).

Interpretation of Common-trend Curves (Figure 10)

The common-trend curves correspond roughly to the degree of preservation. In the better preserved parts, the common-trend values are generally lower, in the less preserved parts they are generally higher. The common-trend curves thus reflect, even in detail, the degree of preservation. This can be explained in the following way. During the process of decay organic matter is lost, resulting in a decrease of dry weight and consequently in an increase in pollen and spore concentrations. Also, the volume decreases, although this is perhaps only due to the sampling method for Søre Salatberget cores A and B as described before; the more the material is decomposed, the more it can be compressed. For the same reason, the loss-on-ignition curve of Stuphallet zone E, where the peat is purely organic and does not contain any sand or clay, is parallel to the common-trend curve.

The common-trend curves indicate that the decay of the organic sediment is not merely a process of aging, for well-preserved layers underlie more decomposed layers. The similarity of the common-trend curves is striking, especially if the distance of about 100 km between Søre Salatberget and Stuphallet is considered. For that reason, any human impact on the common-trend curves can be excluded. The common-trend curves can therefore be interpreted in terms of regional environmental parameters, namely climatic change. Good preservation of the sediment must be due to relatively cold, short, or wet summers, a poor preservation to warm, long, or dry summers. Dips in the common-trend curves reflect phases of unfavorable summers, whereas maxima represent more favorable summers.

Climatic Change in the 17th Century

The comparative diagram (Figure 10) shows a comparison of the common-trend curves with the $^{16}O/^{18}O$ stratigraphy of Dansgaard et al. (1971) and historical data (Hacquebord, 1981, 1983). Stuphallet zone 1 (corresponding to zones B, C, and D in Figures 5 and 9) is not considered, as this core section represents a much earlier period.

Earlier in this paper it was pointed out that zone 2 of Figure 10 represents the period of the Smeerenburg settlement (ca. A.D. 1615 to 1650). In zone 1 the relatively high common-trend values indicate a relatively favorable

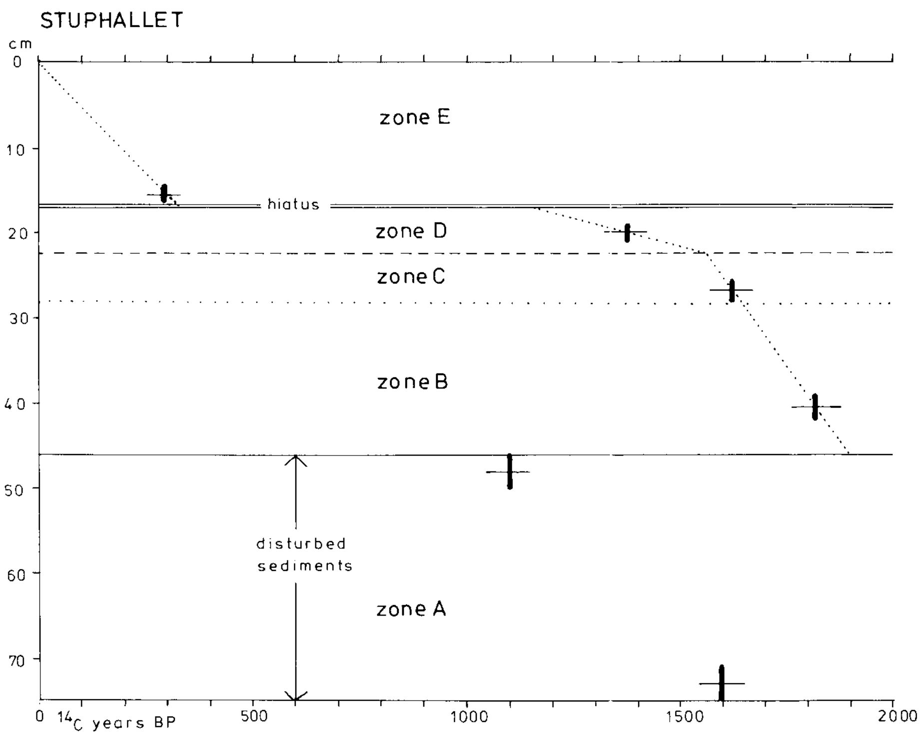

FIGURE 9. Stuphallet age/depth relationship. Horizontal lines are lithological horizons.

climate. The downward trend at the transition zone 1/2 indicates that the climate deteriorated before and at the beginning of the settlement period. The lowest dip is seen at the base of zone 3. This suggests that the climatic minimum was reached after the end of the settlement period. The curves also suggest that the general climatic deterioration during the settlement period was interrupted by a weak minimum and maximum. After the minimum at the base of zone 3, the common-trend curves rise to a pronounced maximum in zone 4, followed by a decline.

In the comparative diagram (Figure 10), the $^{16}O/^{18}O$ curve of Dansgaard et al. (1971) is smoothed by a running mean. The curve, derived from an ice core at Camp Century, Greenland, is interpreted in terms of temperature during ice formation; dips in the curve correspond with temperature minima and peaks with temperature maxima. The 17th-century minima are placed approximately at A.D. 1635 and 1670. This corresponds fairly well with the results given above; in the common-trend curves the corresponding minima are the weak minimum in zone 2 and the pronounced minimum at the base of zone 3.

The archaeological and historical investigations connected with the Smeerenburg project have provided a

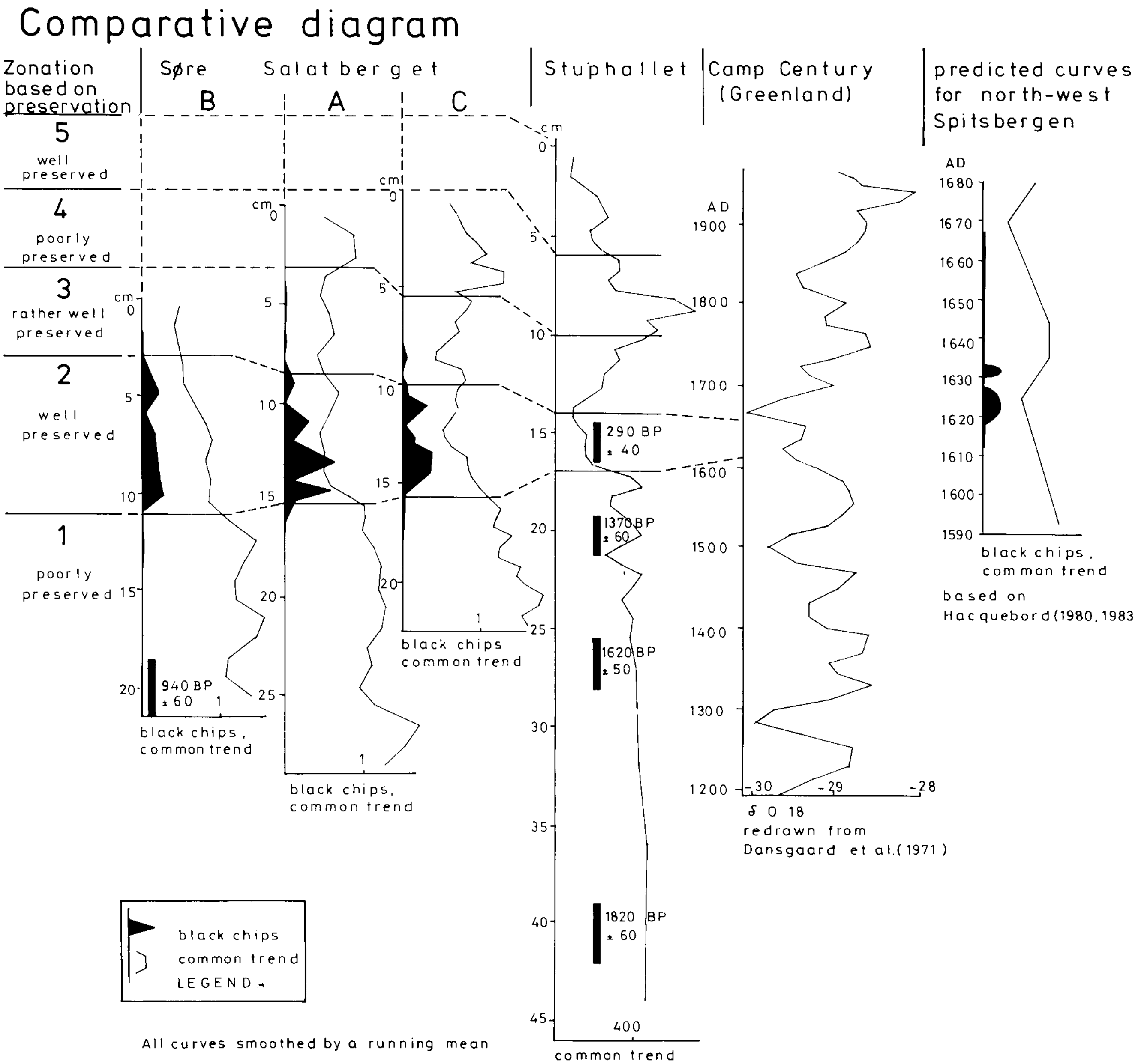

FIGURE 10. Comparative diagram, combining common-trend curves and literature data. For explanation, see text.

wealth of information about the history of Smeerenburg, including indications for climatic change. The paleobotanical data are compared in detail with these historical results in Hacquebord (1984). Here only a few comparisons are presented, based on data published in two summary papers by Hacquebord (1981, 1983). Hacquebord's data suggest that the main periods of activities of the whalers at Smeerenburg were A.D. 1618 to 1628 and A.D. 1630 to 1633. Before and after these periods whaling occurred only elsewhere in northwest Spitsbergen. A predicted curve based on these data is shown in the comparative diagram. Hacquebord also gives some indications of climatic change based on notarial reports on ice drift and ice damage to ships. From these data a predicted common-trend curve is constructed.

Because the most detailed diagram for the period considered is Søre Salatberget diagram C, a comparison of the predicted curves with this diagram will be most fruitful. The comparative diagram shows that a good correlation exists between the predicted curves and the curves of Søre Salatberget diagram C. The sequence of events (i.e., dips and peaks in common-trend and black-chips curves) is the same. However, the relative lengths of the intervals between the events are different. This implies that the time scale of Søre Salatberget diagram C is not linear, whereas the predicted curves are based on a linear time scale. A correlation between predicted curves and the other two Søre Salatberget diagrams is somewhat less clear, but it does not lead to contradictions.

The Stuphallet diagram functions as a check on the results from Søre Salatberget. The Stuphallet curves confirm the climatic trends observed at Søre Salatberget and in the predicted curves. This implies that the radiocarbon date of Stuphallet zone 2 (i.e., zone E in Figures 5 and 9) is of the highest accuracy according to the calibration of Stuiver (1982), as it corresponds exactly with A.D. 1635.

REMARKS ON METHODOLOGY OF ARCTIC PALEOBOTANICAL RESEARCH

This study has shown that a number of approaches in the methodology can be important in the solution of paleobotanical problems in the Arctic. These are listed below, without further discussion.

(1) Paleobotanical research of the last few centuries was successful on three different types of sediment.

(2) Lithological characteristics were important for the interpretation of the diagrams, notably sediment type, degree of preservation, and layering.

(3) The influence of human activity on the natural environment is recorded in a diagram from a former settlement in northwest Spitsbergen. Many pollen types connected with artifacts were found.

(4) In cores 4 km from the former settlement the pollen types connected with artifacts were used as a means of dating; also, a new type of anthropogenic "fossil" was found, called "black chips."

(5) Minor climatic fluctuations are recorded as fluctuations of pollen concentrations in diagrams both from a bird-cliff sediment and from a peat bog.

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APPENDIX

A general account is given of the vegetation and other features of the sites where the surface samples and the cores were collected. On Amsterdam Island, Dr. W. van Leeuwaarden collected the material and data. On Brøggerhalvøya material and data were collected by the author, Mrs. J. F. N. van Leeuwen, P. B. P. M. Bogaers, and A. Farjon. Nomenclature of taxa follows Rønning (1979).

Amsterdam Island (Figure 2)

The vegetation of Amsterdam Island is high arctic, open, scarce, and poor in vascular plant species compared to the central part of Spitsbergen. Apart from the species mentioned below, *Draba* cf. *alpina*, *Luzula arctica* and *L. confusa*, *Poa alpigena*, *Ranunculus nivalis*, and *Saxifraga tenuis* were found. The greater part of the island is formed by a granite mountain with an altitude of 504 m; at the eastern side there is a loamy and sandy plain. The remains of Smeerenburg are found on the eastern tip of the plain, 2 km from the foot of the mountain.

Surface samples 1, 2, 3, and 4 were collected in the eastern part of the plain that shows rather vague, large polygons. The soil is loamy and is covered by 5 to 10 cm or more sand with a clear humus layer. The vegetation is rather sparse and consists mainly of mosses and lichens. Among the vascular plants *Phippsia algida* and *Saxifraga hyperborea* dominate, *Cochlearia officinalis* is abundant, *Saxifraga rivularis* is frequent, and *S. caespitosa*, *S. nivalis*, and *Cerastium regelii* are rare. Sample 2: Vascular plants are very sparse; mainly *Saxifraga rivularis*, *S. hyperborea*, and *Phippsia algida*. Sample 3 was collected in the center of a polygon. Sample 4 was collected on the boundary of two polygons.

Sample 5: The western part of the plain has a slight inclination to the east and is built up of a loamy solifluction soil with vague, downward oriented stripes. Among the rather sparse vascular plants *Phippsia algida* dominates, *Saxifraga oppositifolia*, *S. hyperborea*, *S. rivularis*, *S. cernua*, *S. nivalis*, *Cerastium regelii*, and *Cochlearia officinalis* are frequent, *Saxifraga caespi-*

tosa is occasionally found and *Luzula* sp. is rare. Sample 5 was collected at the transition to the foot of the mountain on a moist site. The vegetation of the mountain slope above the sample is less sparse. Here *Phippsia algida* and *Cerastium regelii* are dominant, *Cochlearia officinalis* and *Saxifraga rivularis* are abundant, *S. nivalis, S. hyperborea, S. foliolosa,* and *S. cernua* are frequent.

Sample 6 was collected at the moist southeastern corner of the mountain; this is the locality on Amsterdam Island with the greatest number of vascular plant species. Here *Luzula* sp. is dominant, *Salix polaris* is frequent, *Saxifraga rivularis* and *Cerastium alpinum* are occasionally present, *Cochlearia officinalis, Phippsia algida, Saxifraga hyperborea, S. caespitosa, S. nivalis, Ranunculus pygmaeus, Poa arctica, Oxyria digyna, Stellaria humifusa, Sagina intermedia, Cardamine bellidifolia, Silene acaulis,* and *Lycopodium selago* are rare.

Sample 7 was collected at the northeastern foot of the mountain on the moraine near Annabreen, a site virtually devoid of vascular plants.

Sample 8 was collected at the flat mountain top, 400 m above sea level. *Luzula* sp. is occasionally found and *Saxifraga rivularis* is very rare.

Sample 9 and cores A, B, and C were collected on Søre Salatberget, a bird cliff of southern aspect near the sea. The cores were taken within one small patch of vegetation of 1 to 2 m² with bird's nests between the rocks. Here abundant vegetation of vascular plants occurs due to eutrophication by birds. *Cochlearia officinalis, Saxifraga cernua,* and *Phippsia algida* are dominant, *Ranunculus pygmaeus, Poa arctica, Cerastium alpinum,* and *Oxyria digyna* are frequent, and *Saxifraga rivularis* is occasionally found. Sample 9 was taken in a vegetation patch nearby where *Cerastium alpinum* and *Ranunculus sulphureus* are the most abundant species.

Sample 10 are the excrements of a couple of Barnacle Geese that were grazing during the summer months on the plain of Amsterdam Island.

Danish Island

Sample 11 was collected in a vegetation rich in mosses, with *Phippsia algida, Saxifraga rivularis, S. hyperborea, S. caespitosa,* and *S. nivalis.*

Brøggerhalvøya

Below Stuphallet six or seven peat bogs of many hectares are located on a nearly horizontal glacial terrace parallel to the Kongsfjord about 30 m asl. The vegetation at the site of the core consists of deep, wet mosses, with vascular plants in between covering 5% of the surface. Among these *Saxifraga caespitosa* dominates, *S. cernua* is abundant, *S. nivalis, Equisetum arvense, Cardamine nymani,* and *Ranunculus sulphureus* are frequent, and *Saxifraga hieraciifolia, S. oppositifolia, Poa alpina, P. arctica, Cochlearia officinalis,* and *Chrysosplenium tetrandrum* are occasionally found.

Some remarks on pollen morphology are thought to be useful here. First, in order to facilitate a comparison between the vegetation description given above and the surface-sample diagram, of a number of pollen types corresponding species from Spitsbergen are mentioned. Second, remarks are made on the variability of some pollen types found in the cores. It was observed that many types are extremely variable, more so than in temperate western Europe. For the beginning arctic researchers it was therefore sometimes difficult to identify individual pollen grains.

Cerastium alpinum: pollen of the species *C. alpinum, C. arcticum, C. regelii.* The surface structure of the grains and the number of pores vary much; pores can be few or even absent.

Cruciferae. The grains are always small and poorly developed. Only in the Stuphallet core a few grains of the *Cardamine* type were found.

Gramineae. In many samples grains with two (exceptionally three or four) pores were found; in many cases the annuli of the pores are then partly overlapping and thus form an 8.

Papaver radicatum: pollen of the species *P. dahlianum.* Most grains are of type B (Kalis, 1979), tricolpate, very small, poorly developed, and many of them without columellae.

Ranunculus: pollen of a type different from Ranunculaceae pollen found in temperate western Europe, produced by the species *R. hyperboreus, R. nivalis, R. pygmaeus, R. sulphureus,* and probably others. Many grains are very small and poorly developed, some without colpi or columellae.

Saxifraga granulata type: pollen of the species *S. caespitosa, S. cernua, S. hyperborea, S. rivularis.*

Saxifraga stellaris type: pollen of the species *S. foliolosa, S. hieraciifolia, S. nivalis, S. tenuis.*

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