Five short pollen diagrams of soils from Jan Mayen, Norway: a testimony of a dynamic landscape

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Five soil cores varying in length from 30 to 42 cm and seven surface samples were analysed for pollen and spores. The soil layers of four cores were probably formed through redeposition of other eroded soils. Only in the Båtvika core is the organic fraction of probable local origin, and here a chronology could be established. A total long-distance pollen influx of 14–22.5 grains/cm^2/year was calculated. Nearly 2,000 long-distance pollen grains were counted; the ratios of the dominant pollen types were calculated. Around Båtvika the past environment was relatively stable; only one major shift in sedimentation environment is apparent from the diagram. In another diagram, expansion of *Taraxacum* species could be correlated with anthropogenic soil disturbance. The former presence of *Lycopodium alpinum* and *Selaginella selaginoides* on Jan Mayen is indicated by frequent spore finds; the latter species has not been found on the island before. Two unknown spore types are discussed.

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During the years 1980–1983, archeological, historical, and biological studies were carried out on north-west Spitsbergen, in the scope of the so-called Smeerenburg-project of the Arctic Centre, Groningen, The Netherlands. The aim of this multidisciplinary project was to investigate and reconstruct the living and working conditions of the 17th-century Dutch whalers in Spitsbergen. Results are published in Hacquebord (1984); the palaeobotanical aspects are described in more detail in Van der Knaap (1985). Another 17th-century Dutch whaling station of importance was situated on Jan Mayen, an isolated island in the Arctic Ocean between Iceland, Spitsbergen, Greenland, and Norway. The Smeerenburg-project has been succeeded by the Jan Mayen-project which functions on the same basis. The aim of the present palynological study was to reconstruct climatic phases during the last few centuries and to determine the influence of the 17th-century whalers on the natural Arctic vegetation of Jan Mayen, as had been done successfully on Spitsbergen (Van der Knaap 1985).

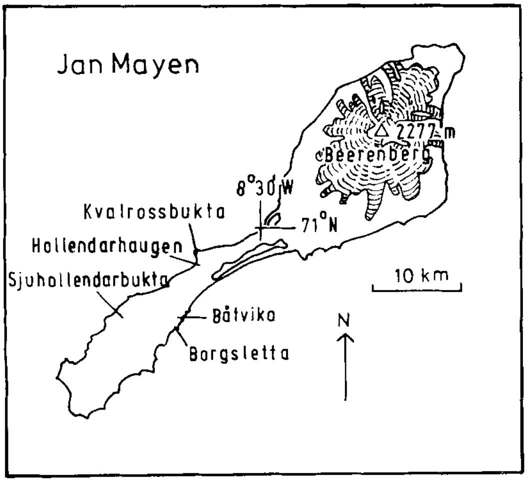

Fig. 1. Map of Jan Mayen indicating the coring localities.

Description of environment and sites

The description is mainly based on Van Franeker (1983). Jan Mayen is an island of volcanic origin at 71°N, 8°30′W, and measures approximately 15 × 50 km. The glacier-covered, 2,200 m high volcano Beerenberg is the highest mountain; the remaining half of the island consists of sandy and rocky plains, hills, and mountains up to approximately 600 m. The climate is mid-arctic and strongly oceanic, and it is characterized by frequent and heavy fogs and storms. The soft, volcanic rocks are very sensitive to erosion; stone and mud slides, sand and dust storms are common. Due to the high permeability of the bedrock, fresh water is rare after snowmelt in 'spring'. Vegetation is scanty and consists mainly of mosses and lichens on the less unstable soils and rocks. Vascular plants are sparse; 64 species are known (Lid 1964; Baagøe & Vestergaard 1974). Peat bogs, fens, and marshes are completely lacking.

During the '*Fulmarus glacialis* Expedition II' Jan-Andries van Franeker and Kees Camphuijsen collected twelve soil cores varying in length from 26 to 50 cm from five localities and seven surface samples; four cores and the surface samples were studied. One core collected by Dr. Louwrens Hacquebord was studied.

Båtvika core. – Collected 7–8–1983. 70°55'9"N, 8°44'0"W. Alt. 15–20 m. Sea distance c. 200 m. C. 1 km N of the Borgsletta core. Just under the outer wires of a mast. In a shallow, dry gully on a terrace below the debris slopes of Trollslottet. The vegetation is relatively rich and consists of mosses, *Festuca rubra, Luzula arcuata, Equisetum arvense, Salix herbacea, Polygonum viviparum*, and some *Oxyria digyna*. Absent here are *Cochlearia officinalis* and *Saxifraga* species.

Borgsletta core. – Collected 7–8–1983. 70°54'48"N, 8°44'40"W. Alt. c. 25 m. Sea distance c. 150 m. C. 1 km S of the Båtvika core. Horizontal area poor in vegetation; mosses and lichens only partly covering the soil. Some *Salix herbacea, Luzula arcuata*, and *Festuca rubra* (veg.) are present, but few other species are found in the surroundings, among them *Saxifraga oppositifolia*.

Hollendarhaugen core. – Collected 24–6–1983. 70°58'0"N, 8°40'50"W. Alt. c. 10 m. Sea distance 300 m. C. 1 km SE of the Kvalrossbukta core. Hollendarhaugen is a low hill with two burial mounds on top, in legend connected with seven Dutch whalers who died on Jan Mayen during the winter of 1633–34 (Brander 1934). In 1931 a wooden cross was erected on the hill. The core was taken from a stony soil between the stones of a dry gully on the slope south of the hill, where some mosses and grass grow.

Sjuhollendarbukta core. – Collected in 1983 by Dr. Louwrens Hacquebord. 70°55' c. 20"N, 8°54'W. Alt. 15–20 m. Sea distance c. 0.5 km. In a dry gully on a green plateau above the sandy bay. Species present at the top of the core (surface c. 2 dm^2) are: *Salix herbacea, Oxyria digyna, Poa alpina vivipara, Cerastium alpinum* (veg.), and *Carex lachenalii*.

Kvalrossbukta core. – Collected 25–6–1983. 70°58'22"N, 8°41'40"W. Alt. c. 15 m. Sea distance c. 10 m. C. 1 km NW of the Hollendarhaugen core. Near the remains of huts of 17th-century Dutch whalers, in rich vegetation at the base of a Fulmar bird colony on the rocks of the Kvalrossen mountain. Abundant vegetation of mosses, grass, *Cochlearia officinalis*, and *Oxyria digyna*. *Taraxacum* spp. and *Saxifraga cernua* are frequent, *S. caespitosa* and other *Saxifraga* species are occasionally found.

Surface samples. – Nos. 1–4 were collected on 23–6–1983 near Hollendarhaugen; see the description of the coring site. No. 1 was taken from a dense moss vegetation just south of the eastern burial mound. No. 2 was taken from a dense moss vegetation NE of the eastern burial mound. The sample consists of a *Sphagnum* species. No. 3 was taken at the coring site. No. 4 is the packing material used for a core (not studied) at the site of No. 1. The sample consists of the moss *Racomitrium* sp. and sand. Surface samples Nos. 5 and 6 were collected on 7–8–1983 around the Båtvika and the Borgsletta cores, respectively; see the description of the coring sites. No. 7 was collected on 7–8–1983 about halfway the sites of Nos. 5 and 6, in Borgdalen on a ridge in the valley. Alt. c. 50 m. Sea distance c. 0.5 km. The vegetation is very open and consists mainly of patches of moss, with some *Salix herbacea, Saxifraga oppositifolia, Luzula arcuata*, and *Cerastium alpinum* in between.

Field sampling methods

Van Franeker and Camphuijsen collected the cores with a home-made gouge 5 cm in diameter and 50 cm long, and packed them in plastic half-tubes. It was difficult to obtain good cores in this way, as most soils appeared to be somewhat incoherent. Hacquebord dug out the core with a spade and packed it in a flower-box of c.

$15 \times 20 \times 60$ cm. In this way the layering of the soil is not disturbed and there is plenty of material for research.

The surface samples consist of a small number of fresh moss plugs each, collected within 1 m^2. The vegetation of coring and surface-sample sites was described in general terms, including plant names varying from family to species, and often a number of common flowering plants around the sites were collected separately and added to the surface samples for identification. These plants were removed before treating the samples.

Laboratory methods

Dry weights of all samples used for pollen analysis and volumes of the samples of the Sjuhollendarbukta and the Hollendarhaugen cores were measured. Pollen and spore concentrations were determined by the addition of tablets containing $11{,}329 \pm 349$ spores of *Lycopodium clavatum* (Stockmarr 1971). Vertical length and quantity of the samples vary somewhat between the cores. In the Båtvika core there are no gaps between the samples, and dry weight is c. 1–1.5 g. In the Borgsletta core the samples have a length of a half to two thirds of a cm, so there remain gaps between the samples, and dry weight is c. 0.5–1 g. In the Hollendarhaugen core there are no gaps between the samples, and the volume is 2–4 cm^3. In the Sjuhollendarbukta core there are no gaps between the samples except between the upper two and the lower three; the two basal and the top sample have a length of 2 cm, the remaining samples are 1 cm, and the volume is c. 1.5 cm^3. In the Kvalrossbukta core the samples have a length of nearly 1 cm and dry weight is c. 2–4 g. Treatment followed in general the methods described by Fægri & Iversen (1975), including sieving over a 0.12 mesh screen and cold overnight treating with 30% HF. The surface samples were treated in the same way, but no *Lycopodium* tablets were added. Not more than one slide was counted for most of the samples. All pollen grains and spores of vascular plants and *Sphagnum* were counted and identified. Verbeek-Reuvers (1977) was used for the identification of Saxifragaceae pollen; two types have been renamed after species growing in the Arctic and on Jan Mayen. *Saxifraga granulata* type is renamed *Saxifraga caespitosa* type and also includes *S. cernua* and *S. rivularis*; *Saxifraga stellaris* type is renamed *Saxifraga nivalis* type and also includes *S. tenuis* and *S. foliolosa*. Umbelliferae pollen was identified by Punt (1984). Two unknown spore types ('Spore P' and 'Spore B') were also counted. In the Båtvika, Borgsletta, and Hollendarhaugen cores, separate samples were taken for the determination of specific weight and of loss-on-ignition. The work was carried out in the Laboratory of Palaeobotany and Palynology, Utrecht, The Netherlands. Two radiocarbon dates were provided by Prof. Dr. W. G. Mook, Isotope Physics Laboratory, Groningen, The Netherlands.

Presentation of results

The results are presented as concentration diagrams for all cores (Figs. 3–7) and a percentage diagram for the surface samples (Fig. 2). Pollen and spore types were grouped into two categories, as in earlier work (Van der Knaap 1985): *local-regional component*, pollen and spores presumed to be derived from plants growing on Jan Mayen, and *long-distance component*, pollen and spores originating in areas outside Jan Mayen. The two unknown types 'Spore P' and 'Spore B' are plotted separately from the two components. Zones were established in the diagrams for the ease of reference. The criterion for zonation was that the zones should be homogeneous in pollen content and differing from adjacent zones. At the far right side of the diagrams are shown the total cumulative long-distance values on 1 cm^2. In the Sjuhollendarbukta and Hollendarhaugen diagrams these values could be calculated directly from the concentration values (number of grains in 1 cm^3); in the other diagrams the concentration values (number of grains in 1 g dried sediment) first had to be converted into number of grains in 1 cm^3 by means of the calculated and interpolated specific-weight values.

The lithology of the cores is described at the far left side of the diagrams (Figs. 3–7). Unbroken horizontal lines indicate abrupt and clear transitions between soil layers, broken lines indicate gradual and/or indistinct transitions. The artefact in zone Hollendarhaugen-3 at 9–11 cm is a thin piece of wood $2.5 \times 1.5 \times 0.2$ cm. The layering in the upper part (c. 8–13 cm) of this zone is somewhat irregular.

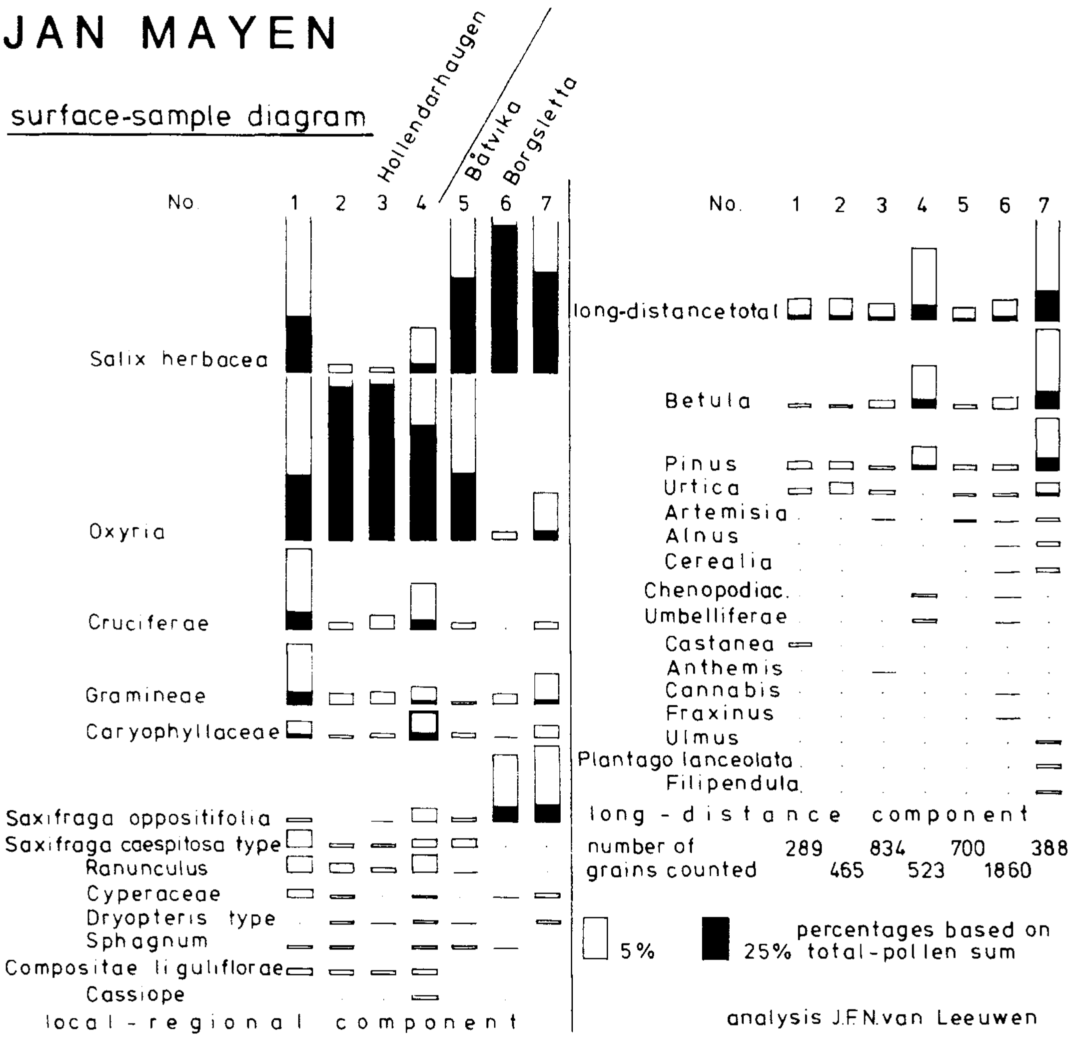

Fig. 2. Surface-sample percentage diagram.

In the comparative summary diagram (Fig. 9), histograms of the dominant pollen types are given. Pollen values are calculated as percentages of a total long-distance pollen sum. All samples of a pollen zone in the concentration diagrams (Figs. 3–7) are added together in order to attain a sufficient number of long-distance pollen grains. Consequently, each spectrum in the comparative summary diagram represents an entire zone of a concentration diagram. For the vertical axis of the comparative summary diagram are used the total cumulative long-distance values on 1 cm^{2}, and not, as in the concentration diagrams, depth in cm.

Results

Surface samples

In spite of the incomplete vegetation data of the surface sample sites, some interesting relationships can be noted.

Polygonum viviparum seems to produce very little pollen on Jan Mayen, although the species is widespread (Lid 1964). It grows at the site of sample No. 5 (Båtvika core), but no pollen turned up in any of the surface samples or cores. *Equisetum arvense*, even more widespread on Jan Mayen (Lid 1964), seems to be a low spore pro-

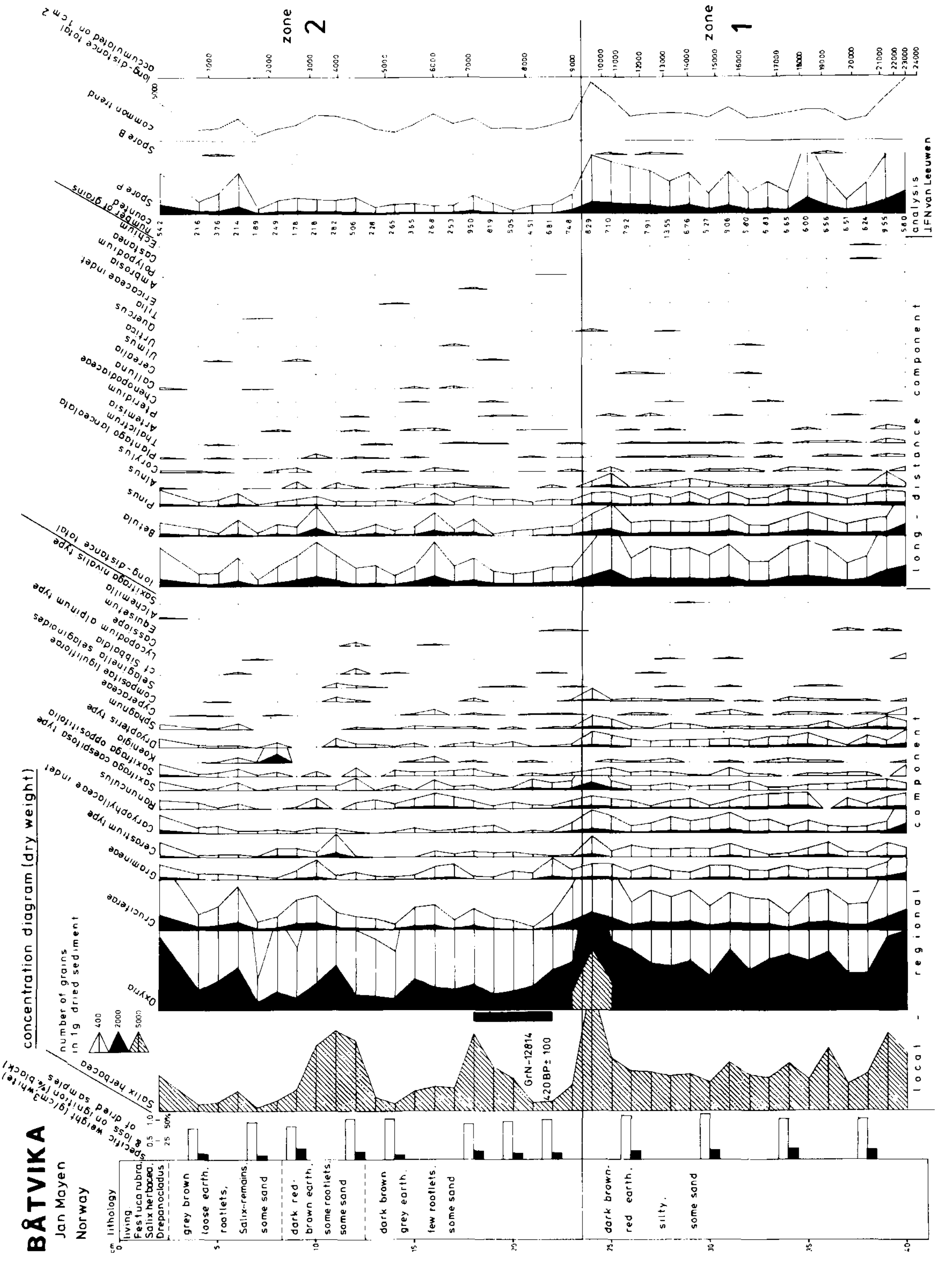

Fig. 3. Båtvika concentration diagram.

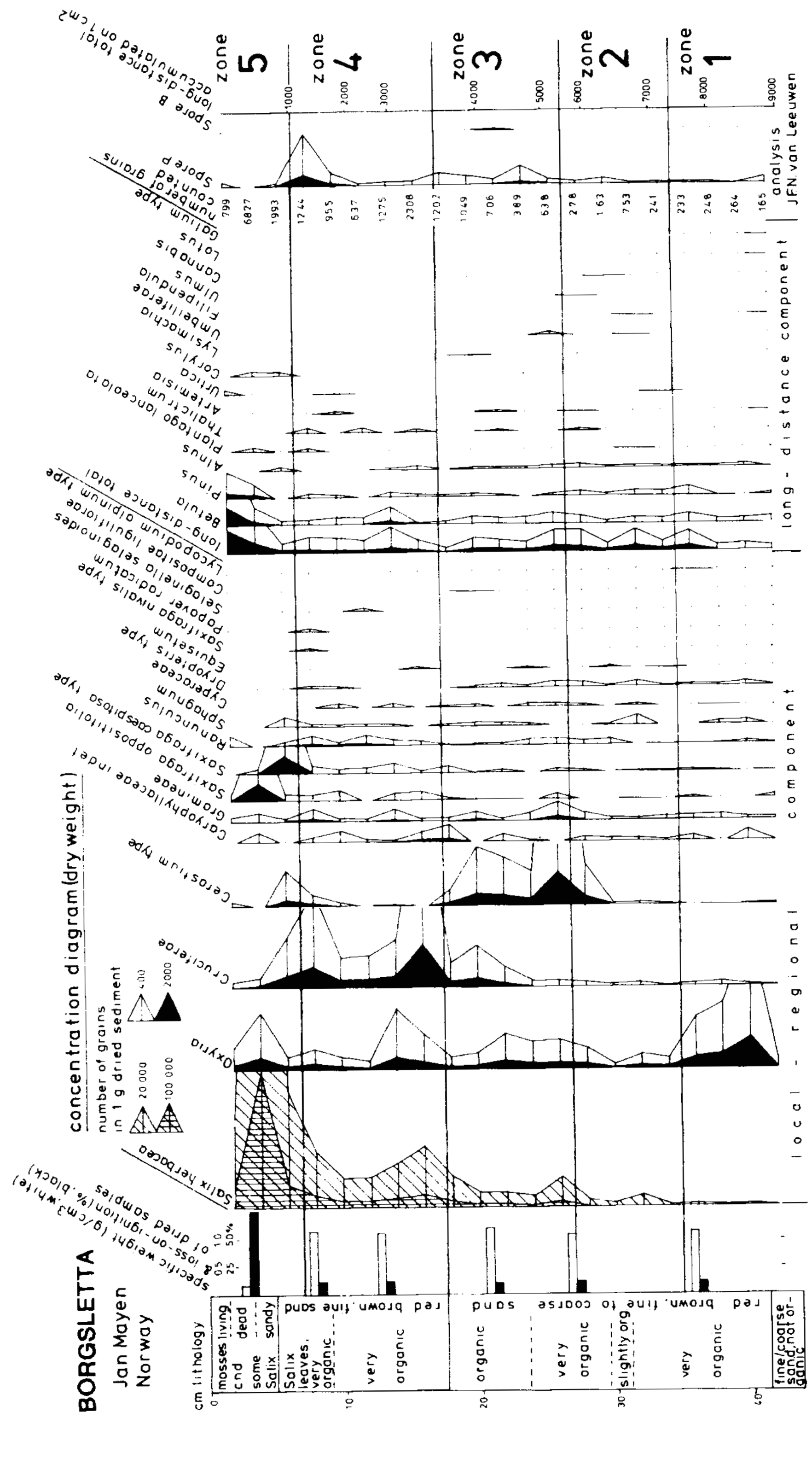

Fig. 4. Borgsletta concentration diagram.

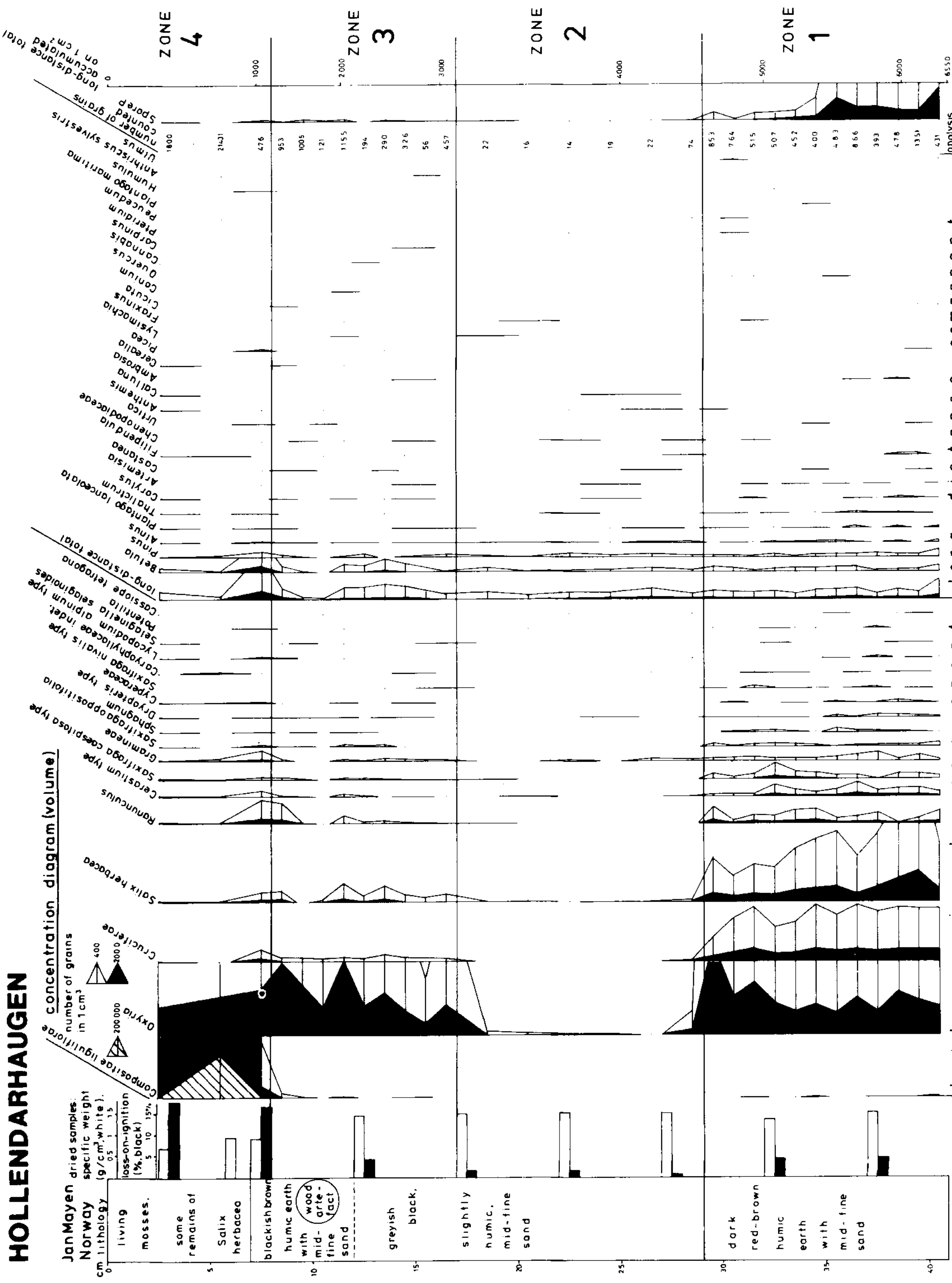

Fig. 5. Hollendarhaugen concentration diagram.

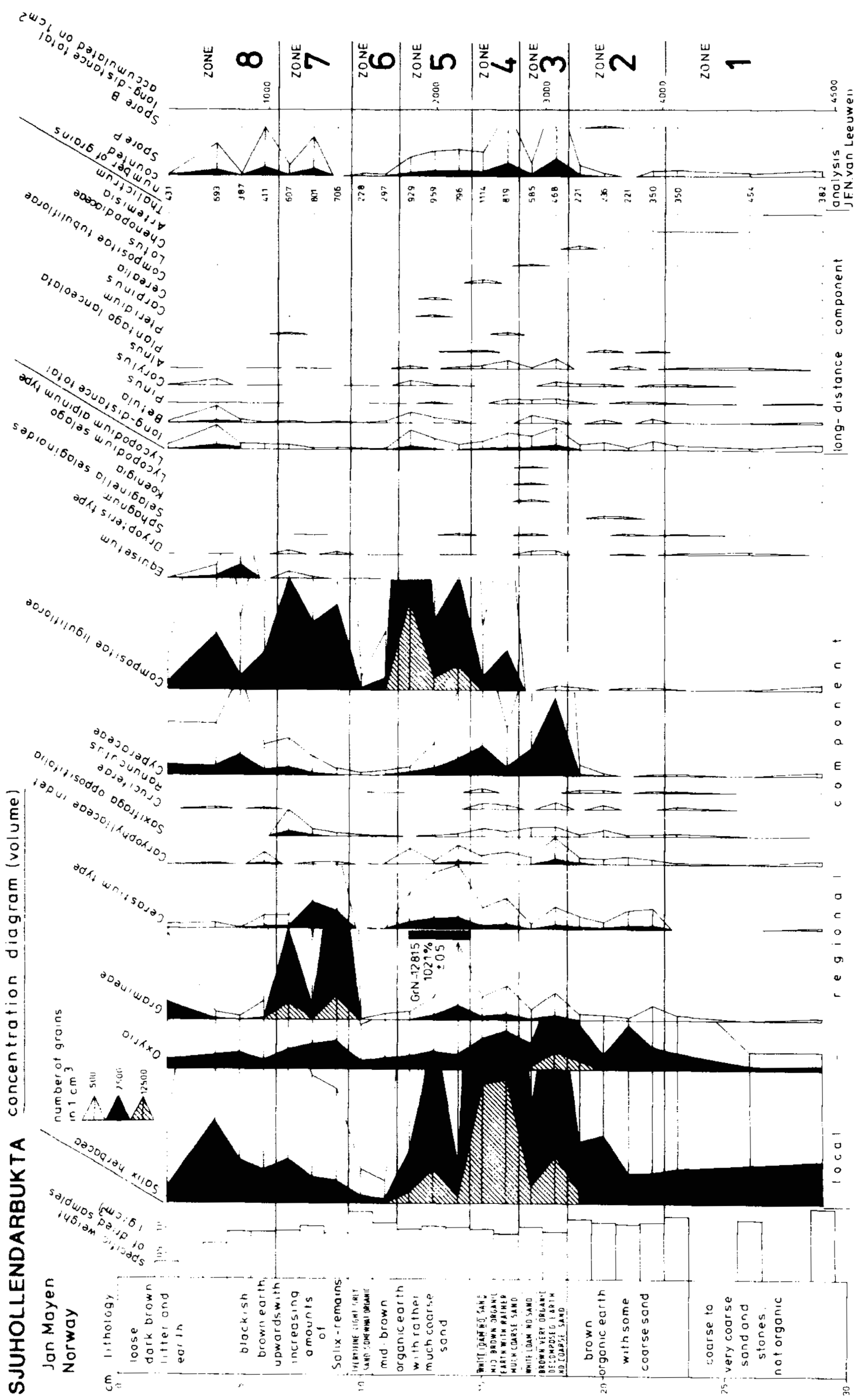

Fig. 6. Sjuhollendarbukta concentration diagram.

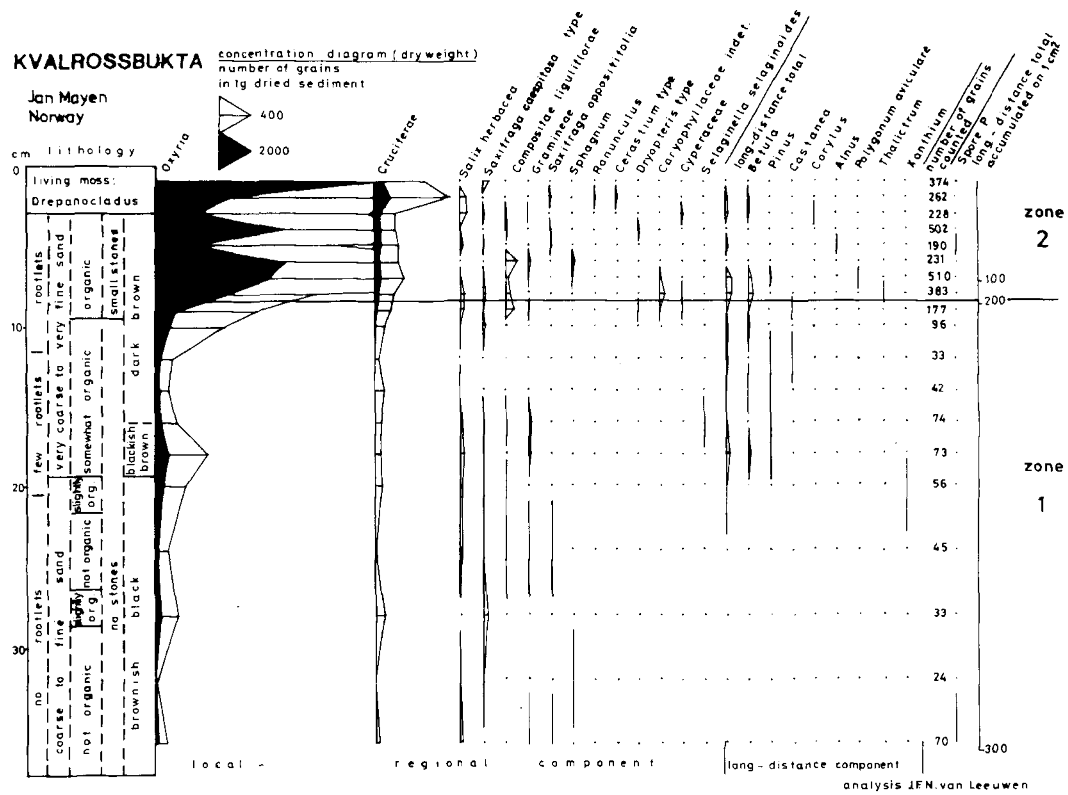

Fig. 7. Kvalrossbukta concentration diagram.

ducer; it also grows at the site of No. 5, but spores are absent from all the surface samples and low in concentration in all diagrams.

As surface samples Nos. 3, 5, and 6 are taken at coring sites, it is not surprising that these spectra are similar to the upper spectra of the associated cores. An exception is the low value of Cruciferae pollen compared to the Båtvika core; *Cochlearia officinalis* (Cruciferae), however, is absent from the present-day vegetation of the site.

It should be noted that *Oxyria* is the dominant pollen type in the Hollendarhaugen core, in surface samples Nos. 1–4 taken nearby, and in the nearby Kvalrossbukta core, and that *Salix herbacea* is the dominant pollen type in surface samples Nos. 5–7 and in the nearby Båtvika and Borgsletta cores.

Lithology

The soil stratigraphy is different in all thirteen collected cores. None of them is homogeneous throughout; they are built up of 2–8 (mean: 6) layers differing in colour, proportions of organic material and sand, grain sizes of the sand, and type and degree of preservation of plant material. Many transitions between soil layers are abrupt. Such a stratigraphy is indicative of a strongly fluctuating sedimentation environment, as might be expected on this island with its harsh climate and soft rocks. While interpreting the diagrams, it is important to remember that the soil layers can differ in sedimentation rate, that part of the organic material (including pollen and spores) can be redeposited from eroded soil, and that there can be sedimentation gaps or erosion phases at all abrupt transitions between the layers.

The Båtvika core is a possible exception. The zone transition is the only discontinuity in both bio- and lithostratigraphy; there are no lithological indications of irregularities in the sedimentation rate within the zones. Landscape characteristics suggest that erosion takes place on the barren, stony hill slopes, and not on the densely moss-grown terrace where the core was taken. Therefore, the organic component of the sediment is probably of local origin.

Table 1.

	Surface samples	Båtvika	Borgsletta	Hollendarhaugen	Sjuhollendarbukta	Kvalrossbukta	Total (cores + surface samples)
Total long-distance pollen, number of grains counted	181	859	230	487	133	27.5	1918
total arboreal pollen, %	94.5	84.0	90.4	87.5	91.0	78.2	87.0
Betula, %	54.7	44.7	52.6	46.2	47.4	61.8	47.4
Pinus, %	**36.5**	28.3	24.3	24.0	**14.3**	12.7	26.3
Alnus, %	**1.1**	10.0	10.9	8.6	12.8	3.6	9.0
Corylus, %	**0.6**	4.3	1.3	2.9	**15.8**	–	4.0
Plantago lanceolata, %	1.1	3.3	1.3	3.5	3.0	–	2.8
Thalictrum, %	–	2.8	3.5	2.7	0.8	3.6	2.5
Artemisia, %	2.8	1.6	1.7	1.4	0.8	–	1.6
Chenopodiaceae, %	1.1	0.6	–	1.2	0.8	–	0.7
Other types, %	2.2	4.4	4.4	**9.4**	4.5	**18.3**	5.7

Chronology

Undisturbed sediments without sedimentation gaps are needed for the determination of sedimentation rates and of pollen influx values. Only in zone Båtvika-2 are these requirements likely to be fulfilled; here no lithological or biostratigraphical horizons are present and pollen is probably not reworked. The calibrated radiocarbon date in this zone is A.D. 1410–1630 (Stuiver 1982; Stuiver & Pearson 1987); this implies a sedimentation rate of 3.5–5.7 cm/100 years and a total long-distance pollen influx of 14–22.5 grains/cm^2/year. This corresponds very well with total long-distance influx rates in lakes in south Greenland (Fredskild 1973). If the long-distance influx has been constant throughout, then the dating of the base of zone Båtvika-1 will be between A.D. 270 and 920, or even earlier if there is a hiatus at the zone border.

The artefact in zone Hollendarhaugen-3 at 9–11 cm must have been brought up together with the sand now forming the disturbed layer between c. 8 and 13 cm, during the erection of the wooden cross in 1931. The base of the overlying and apparently undisturbed layers is situated at c. 7–8 cm; this results in a total long-distance pollen influx of 15–30 grains/cm^2/year since 1931. This agrees with the influx values found in zone Båtvika-2.

The radiocarbon date in zone Sjuhollendarbukta-5 is given in percentages of radioactivity instead of radiocarbon years, and is from this century. The distinct horizontal layering of the sediment may indicate that the stratigraphy is undisturbed. If this is the case, then the sediment has at least partly been redeposited by wind or water from different source areas.

The accumulation values of total long-distance pollen, used as the vertical axis of Fig. 8, probably do not provide a means of chronological correlation between the diagrams. The requirement of an uninterrupted sedimentation of non-redeposited material is in most cores probably not fulfilled.

Long-distance pollen

A total of 1,918 long-distance pollen grains was counted in all cores and surface samples together. In Table 1, percentages based on a total long-distance pollen sum are listed for the cores and surface samples of the eight types of which more than ten grains were found. Average percentages are listed in the last column. The 0.95% confidence limits were calculated for all percentages by means of the nomograms in Maher (1972); bold figures are values that differ significantly from the average value of the same type.

An explanation of the deviations must remain very tentative. It could be that the winds carrying the long-distance pollen found in the surface samples were from more northern directions compared to an average situation, and those in the Sjuhollendarbukta core from more southern directions. This would explain the relatively high percentage values of *Pinus* in the surface samples and the low values in the Sjuhollendarbukta core. However, indications are totally absent in any of the diagrams of periods differing qualitatively in long-distance pollen.

Båtvika: past environment

It can be observed in the Båtvika diagram that the general trends of the curves are similar. This 'common trend' has been presented as a separate curve in order to facilitate interpretation. The common-trend curve was calculated as follows: 1. The influence of the dominant pollen types *Salix herbacea*, *Oxyria*, and Cruciferae is reduced by dividing concentrations by a number, fixed for each type in such a way that a mean concentration of 200 grains/g, similar to that of many other types, is reached; 2. The peak concentration of *Koenigia* at 8 cm, that does not follow the observed common trend, is omitted; 3. The total concentration values of all types are plotted at every level, resulting in a curve, defined here as the common-trend curve.

The fluctuations of the common-trend values depend on fluctuations in either accumulation rates of the sediment, or pollen influx values (number of grains/cm^2/year). The last is highly improbable for several reasons. The first reason is that the trends observed in the total long-distance curve and in the curves of the local-regional component are similar, as is shown graphically in Fig. 8. The total long-distance values are plotted here against the 'common-trend values minus total long-distance values', as the last are a constituent part of the first. Only the top sample of zone Båtvika-1 is far removed from a predicted linear relationship; the total long-distance value is about half the predicted value. It can hardly be assumed that the two

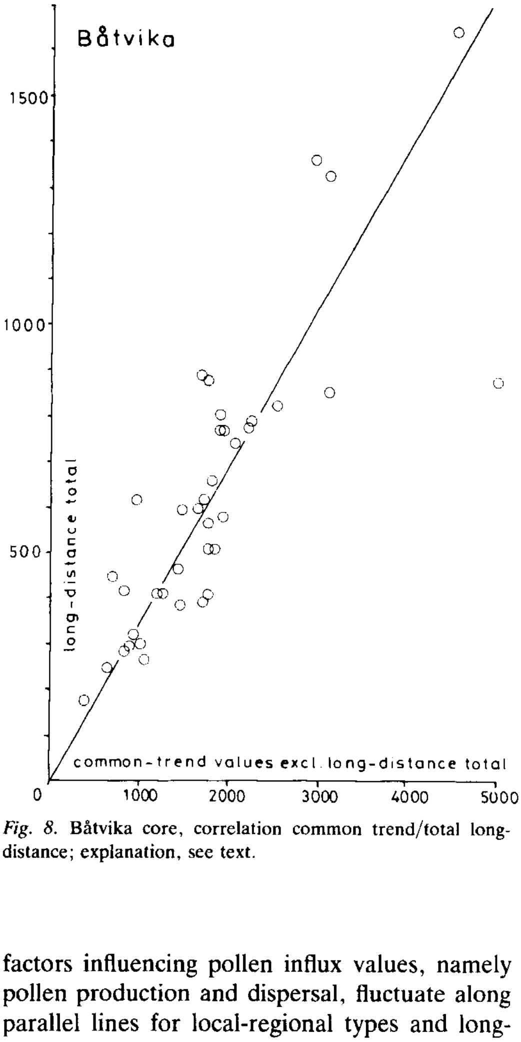

Fig. 8. Båtvika core, correlation common trend/total long-distance; explanation, see text.

factors influencing pollen influx values, namely pollen production and dispersal, fluctuate along parallel lines for local-regional types and long-distance types. Redeposition of pollen from eroded organic soils, a possible cause for the observed common trends, has probably not taken place, as shown above. The final conclusion is that the direct cause of the observed common trend is fluctuation in the deposition rates of the total organic and inorganic sediment.

In the common-trend curve a sharp decline can be observed at the zone transition, and minor fluctuations within each zone. The sharp decline indicates a major shift in the deposition environment, resulting in lower concentration values of pollen and spores. A possible event could be a nearby landslide, resulting in an enlarged source area of the sand to be deposited. At the top of zone Båtvika-1 the common-trend curve reaches a maximum, indicating an event possibly related to an inferred major environmental shift. The

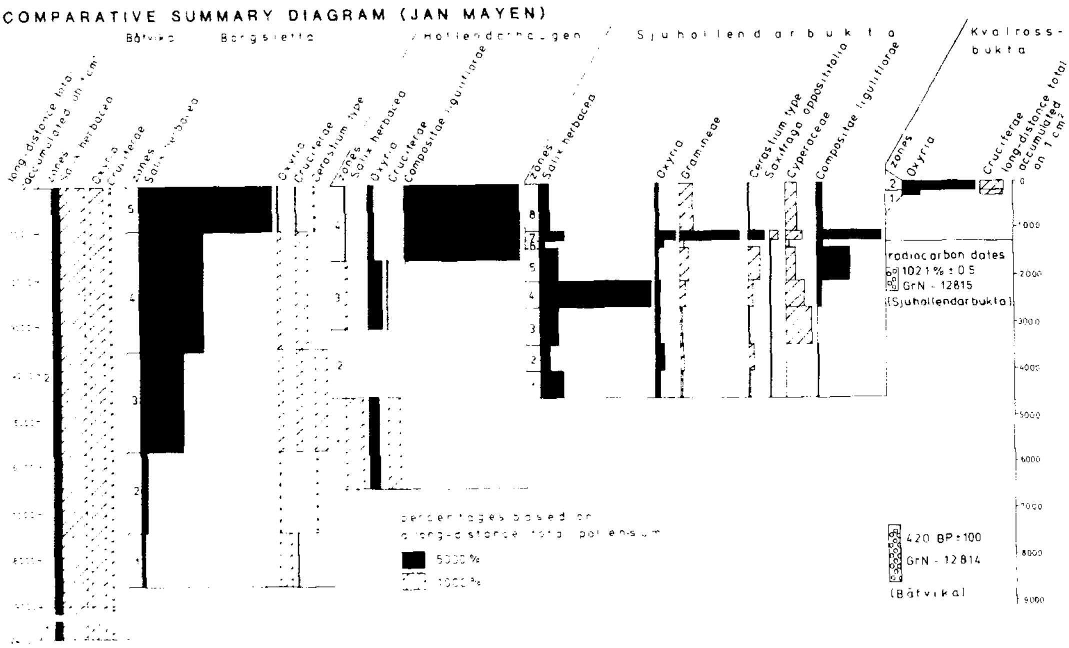

Fig. 9. Comparative summary diagram. The cumulative long-distance pollen values used as the vertical axis (extreme left) probably do not provide a relative time scale; explanation, see text.

minor fluctuations in the common-trend curve are possibly connected with climatic factors influencing sand deposition rates, such as wind velocities and wind directions. The data, however, do not allow a more detailed climatic interpretation.

Past vegetation

The best base for interpretation in terms of past vegetation are pollen influx values (number of grains/cm^2/year). These values cannot be calculated from the available data. Instead, percentage values based on a total long-distance pollen sum are used (Fig. 9); such values are only dependent on variations in total long-distance pollen influx values, and are independent of accumulation rates of the studied sediments, and of each other. Only major differences between pollen zones are considered to be significant, for two reasons; 1. Statistically speaking, the percentages have low reliability because most values exceed 100% and because the pollen sum is often rather low; 2. There has probably been some variation in the total long-distance pollen influx during the last millennia, as has been the case, for example, in Greenland (Fredskild 1984), and on Spitsbergen and Bjørnøya (Hyvärinen 1972). With the exception of the two identical pollen zones Båtvika-1 and -2, all zones differ strongly from each other in percentage values of one or more pollen types. This must be due to differences in past vegetation. Interpretation of the data in terms of past vegetation composition is independent of the degree to which the sediments were redeposited from eroded soils, provided that pollen and spores were not sorted during redeposition. Any possible redeposition would cause uncertainty in determining the age and location of former vegetation. So the data cannot be interpreted in terms of vegetation succession, sediment formation, or changes in environmental factors, because a chronological base is lacking and erosion/sedimentation patterns have not been studied in detail. Only a few features of the diagrams will be discussed here.

Dandelions (*Taraxacum* spp.) are the only representatives of the Compositae liguliflorae on Jan Mayen. Long-distance transport of this pollen type can only be exceptional; most grains found in the cores must therefore be derived from dandelions from the island. Brander (1934) tells us that the dandelions on Jan Mayen were probably introduced by the 17th-century Dutch whalers.

The regular presence of pollen of Compositae liguliflorae in both zones of the Båtvika diagram indicates, however, that dandelions grew on the island long before the discovery of Jan Mayen. Dandelions are generally favoured by disturbance and manuring of the soil; the explosive expansion seen in zone Hollendarhaugen-4 therefore probably occurred at the time of the erection of the wooden cross in 1931. The expansion of dandelions seen in zone Sjuhollendarbukta-5 cannot directly be correlated with historical events. The radiocarbon date in this zone indicates that the whole sequence from this level to the top of the core might be recent. An alternative explanation is that environmental pollution associated with the whaling activities of the 17th-century Dutch whalers might have caused an explosive expansion and flowering of the native Jan Mayen dandelions; such an observation could have been the basis of Brander's remark.

Sterile plants of *Lycopodium alpinum* were found only once on Jan Mayen (Baagøe & Vestergaard 1974). Spores of *Lycopodium alpinum* type were found in 12 samples in nearly all cores. Long-distance transport can only be responsible for one or very few spores; this means that fertile plants were (or are) present on the island.

So far, *Selaginella selaginoides* has not been found on Jan Mayen. The frequent spore finds, especially in the Båtvika core, indicate that the species has grown on the island for centuries, as long-distance transport can only be responsible for very few grains. The plant, which resembles and frequently grows between mosses, is easily overlooked in the field.

Two unknown spore types, called here 'Spore P' and 'Spore B', were counted. For details of Spore P, see photographs Fig. 10. The spores are thin-walled and about 30 mμ. One side of the grain has an indistinct trilete mark, the other side has a fingerprint-like structure somewhat reminiscent of *Polemonium* pollen grains. The grains are often folded, but otherwise fairly constant in characteristics. The author also found two grains in the Spitsbergen core 'Søre Salatberget-C' at 13.5 cm (Van der Knaap 1985). The frequent *Polemonium* pollen finds of Zelikson (1971) in a Spitsbergen peat bog could be a misidentification of this Spore P.

Spore B was found only with a few grains. In an unpublished study of a core from Angmagssalik (Greenland) many were found by the author; this type will be discussed and described in more detail in a later publication. Spore B is rather variable. Some forms are nearly identical to *Botrychium* spores, but in most grains the surface structure and the trilete mark are less distinct.

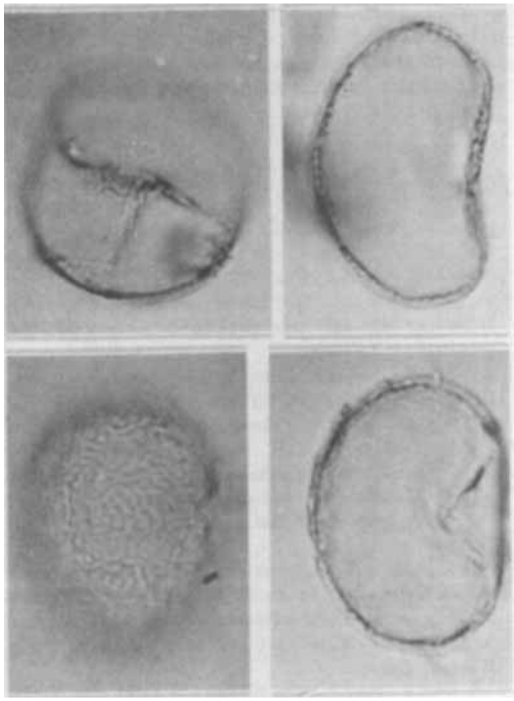

Fig. 10. Spore P; c. 1250×.

General conclusion

The cores clearly reflect a very dynamic environment. Erosion and sedimentation are the dominant factors that determine the soil stratigraphy. It is difficult to establish a chronology. This could probably be done more easily when studying longer cores (up to some m) from favourable sites. It will be possible then to study vegetation succession; it is seen in the present study that soil layers differ generally in pollen and spore assemblages, and these can be translated to some degree in past vegetation types. Minor climatic fluctuations are in the sediments apparently obscured or not reflected. It is doubtful whether sediments can be found on Jan Mayen in which climatic fluctuations of the last few centuries to millennia can be studied successfully; peat bogs and suitable lake sediments seem to be absent.

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