NORSK POLARINSTITUTT

ÅRBOK 1973

NORSK POLARINSTITUTT
OSLO 1975

DET KONGELIGE DEPARTEMENT FOR INDUSTRI OG HÅNDVERK

NORSK POLARINSTITUTT
Rolfstangveien 12, Snarøya, 1330 Oslo Lufthavn, *Norway*

SALG AV BØKER

Bøkene selges gjennom bokhandlere, eller bestilles direkte fra:

SALE OF BOOKS

The books are sold through bookshops, or may be ordered directly from:

UNIVERSITETSFORLAGET

Postboks 307
Blindern, Oslo 3
Norway

16 Pall Mall
London SW1
England

P.O. Box 142
Boston, Mass. 02113
USA

Publikasjonsliste, som også omfatter land- og sjøkart, kan sendes på anmodning.

List of publications, including maps and charts, may be sent on request.

NORSK POLARINSTITUTT

ÅRBOK
1973

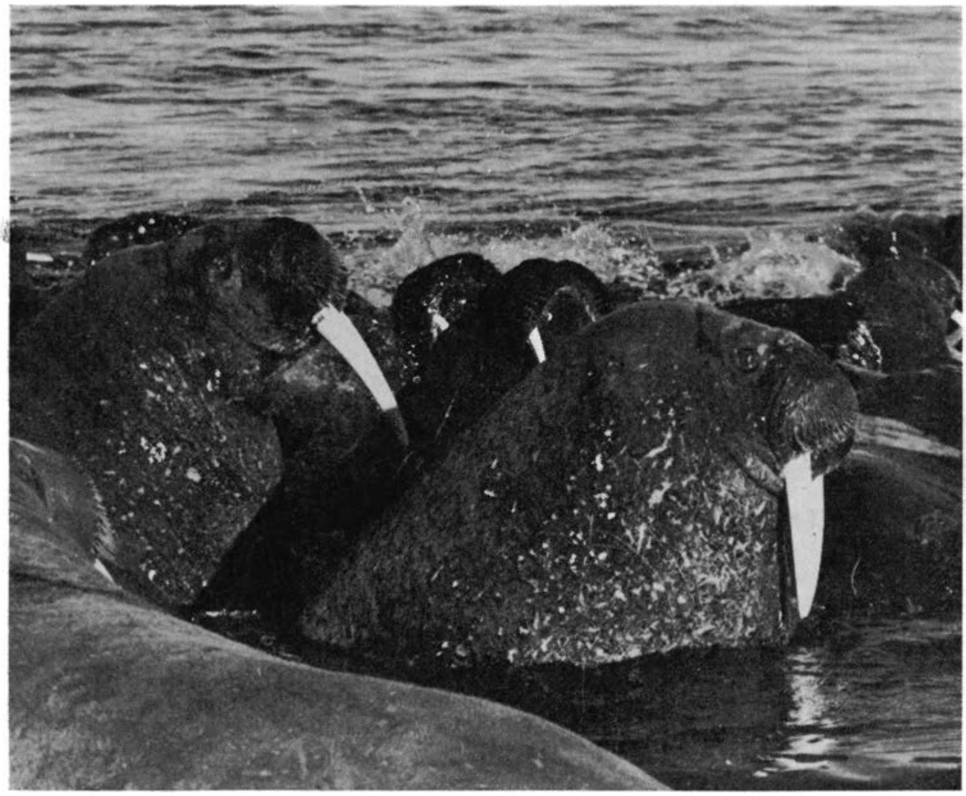
NORSK POLARINSTITUTT
OSLO 1975

Utgitt ved TORE GJELSVIK – direktør

Redaksjonssekretær: ANNEMOR BREKKE

Fagkomité:
TORE GJELSVIK, PETER HAGEVOLD, VIDAR HISDAL,
THOR LARSEN

Trykt januar 1975



Hvalross på Moffen.
Walrus on Moffen.

Innholdsfortegnelse

Some features of the distribution of cloudiness and duration of sunshine at Norwegian Arctic stations

By Vidar Hisdal

Contents

Abstract

The present discussion of cloudiness and duration of sunshine at four Norwegian Arctic stations (Isfjord Radio, Hopen, Bjørnøya, and Jan Mayen) is primarily based on a study of frequency distributions. A comparatively simple graphical representation of these distributions is obtained by applying a transformation function, which previously, for stations in lower latitudes, has proved to give approximately normal distributions for observed cloud amounts and their daily means, as well as for the daily relative duration of sunshine. There seem to be valid reasons for assuming that certain systematic deviations of the transformed frequency distributions from normality for the Arctic stations to a large extent are due to biases caused by special observation difficulties encountered in these regions. As would be expected, a clear or predominantly clear sky is much more frequent at Isfjord Radio and Hopen than at the two stations farther south, and more frequent during spring than during the summer and autumn months. The mean daily change in cloudiness is comparatively small. Special features of the relationship between the frequency distribution of mean daily cloud amount and that of the daily relative duration of sunshine are considered. The low solar altitude in Arctic regions, and the fact that the sun stays above the horizon most of the summer season, are likely to be important factors in this connection. It is shown how the frequency distributions of cloud amount and relative duration of sunshine may be described by simple, linear equations, and a rapid method of estimating mean values on the basis of the frequency distributions is outlined.

Introduction

Mean cloud amount and duration of sunshine, and particularly the relationship between these elements and the global solar radiation, have been discussed by several authors. Extensive studies of data from Norwegian stations have been published by SCHIELDRUP PAULSEN (1950, 1953) and SPINNANGR (1968).

In the present discussion cloudiness and duration of sunshine are considered from a somewhat different point of view, as more stress is laid on studying the frequency distributions of observed values, than on the relationship between average values.

The typical frequency distribution in intermediate latitudes of observed cloud amounts has the greatest number of cases for a completely overcast sky, while cases with a clear or nearly clear sky may show a more or less well developed secondary maximum. Mean daily cloud amounts as well as daily values of relative duration of sunshine present frequency distributions of a similar form, but, as would be expected, with far less pronounced maxima.

Mean values of such U- or J-shaped distributions are evidently not very informative, and should be supplemented by other statistics, or preferably by the frequency distribution itself. In a previous paper (HISDAL 1974) it is shown, by means of data from Swiss and Norwegian stations, that it is possible, at least in a great number of cases, to give a relatively simple representation of these frequency distributions by transforming them into approximately normal distributions, using a transformation function of the form:

$$y = \ln \frac{z}{100 - z}$$

where z is the percentage value of the variate.

The following investigation is based on observations from the four Norwegian Arctic stations: Isfjord Radio (78°04′N, 13°38′E), Hopen (76°31′N, 25°00′E), Bjørnøya (74°30′N, 19°00′E), and Jan Mayen (70°56′N, 08°40′W). To some extent data from Tromsø, Bergen, and Oslo are used as a basis of comparison.

In addition to climatological considerations, we want to judge the applicability for Arctic stations of the above transformation function.

In these regions relatively frequent occurrence of fog during the summer months, and lack of light during the winter season, may often make it difficult, or even impossible, to obtain reliable estimates of the cloudiness, and are likely to cause a certain bias of the observation material.

Concerning the recorded duration of sunshine, the comparatively low solar altitude, even during the middle of day in summer, and the fact that the sun stays above the horizon day and night during the larger part of the summer season, are likely to give rise to special features as well.

Frequency distributions of cloud amount

Noon observations

We first consider the noon observations, and furthermore, in order to reduce sampling fluctuations as far as possible, we combine the months June to August and December to February. A study of data for individual months indicates that the annual changes that take place within each of these seasons are sufficiently small to be neglected in a discussion of general features of the cloudiness distributions.

In the years prior to 1949 the cloud amount (N) was reported as the number of tenths of the sky covered by clouds, with the additional rule that N = 0 and N = 10 mean a completely clear and completely overcast sky, respectively. Cases where it is not possible to judge the cloud amount are included in the class N = 10.

For the 20-year period 1929–48 data from the following observation periods were available: Isfjord Radio (1935–40, 1947–48), Bjørnøya (1931–40, 1946–48), and Jan Mayen (1929–40, 1947–48). (Hopen is disregarded, as only two years of observation were available for this station.) The observation periods are not very long, nor are they the same for all stations, and we confine ourselves here to consider the summer seasons only.

The frequency distributions of the observations at 1400 MET are shown in a normal probability diagram, Fig. 1, where the abscissa gives cumulative percentages, and the ordinate is divided according to the transformation function y = f(z) given above, z being the percentage cloud amount. The limit

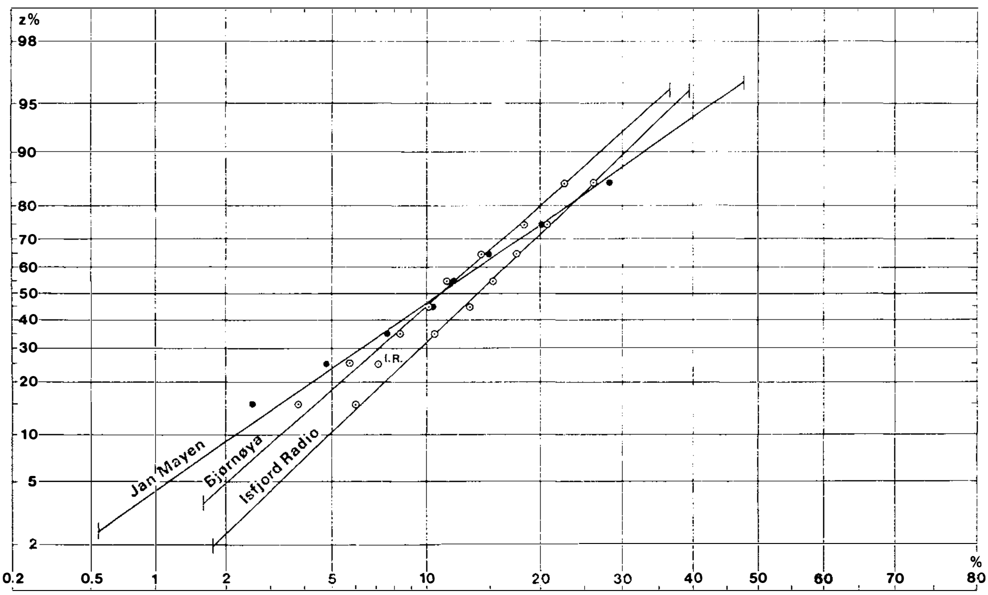


Fig. 1. *Cumulative percentage frequencies of cloud amount at 1400 MET for June–August represented in a normal probability diagram. Cloud amount observed in tenths, indicated as percentages (z) along the ordinate. The observation periods (all prior to 1949) are specified in the text.*

between N = 0 and N = 1, and that between N = 9 and N = 10 must be considered as non-defined, and the frequencies of $N<1$ and of $N<10$ are indicated by small vertical lines in the figure. The straight lines, which represent normal distributions in this type of diagrams, are drawn through the points "by eye". In doing this somewhat more importance is attached to the points near the median than to points in the extreme parts of the scale, where the variance of the quantiles is greatest. In spite of the subjective character of this graphical estimation of the hypothetical normal distribution, the points are generally situated so closely along straight lines, that the freedom of choice when determining the course of the lines is not very great. The points representing cloud amounts less than 15% and less than 25% lie to the left of the straight lines, and seem to form the most conspicuous systematic deviation from the straight lines fitted to the points representing higher cloud amounts. This may be due to the fact that all cases with "cloud amount unobtainable" (meaning normally "fog" during the summer season) are included in the code figure N = 10, while no doubt a certain fraction of these cases in reality belongs to lower cloud amount classes. We shall return to this point later.

Systematic observation errors are likely to be responsible for some of the more marked irregularities. This applies e.g. to the suspiciously low frequency of N = 2 in relation to N = 3 at Isfjord Radio, which is likely to be the result of "a weakness" on the part of several observers for code figure 3. (This figure seems, as a whole, to be quite popular when estimating cloudiness.) As would be expected, Isfjord Radio has the highest frequency of low and moderate cloud amounts. It is more surprising that Jan Mayen has the lowest frequency of both very low and very high cloud amounts. However, since the observation periods for the three stations are not the same, we shall not here enter into a comparative climatological discussion.

In accordance with the new, internationally adopted cloudiness scale, the cloud amount at Norwegian stations is from 1 January 1949 recorded as the number of eighths ("oktas") of the area of the sky covered by clouds. Regarding the difficulty in connection with the unfortunate definition of the limit between scale numbers 1 and 2, and that between 6 and 7, reference is made to the discussion mentioned previously (Hisdal 1974). We here put this limit equal to 1.5 and 6.5 oktas, respectively.

Fig. 2 (upper part) shows the frequency distribution of the noon observations (1300 MET) in June—August for the period 1949–68. "Cloud amount unobtainable" (N = 9) is included in the class N = 8. For the sake of comparison the corresponding distribution for Tromsø and Oslo are indicated by broken lines. We see that during this period Hopen is distinguished by having the highest frequency of clear skies as well as (together with Bjørnøya) of overcast skies, cases with a partly overcast sky being comparatively seldom. The cloudiness at Bjørnøya and Jan Mayen does not seem to be appreciably different. The conditions at the latter station are slightly more favourable in the sense that the frequency of large cloud amounts are somewhat smaller. Isfjord Radio has the smallest percentage of an overcast sky. However, even here an overcast or al-

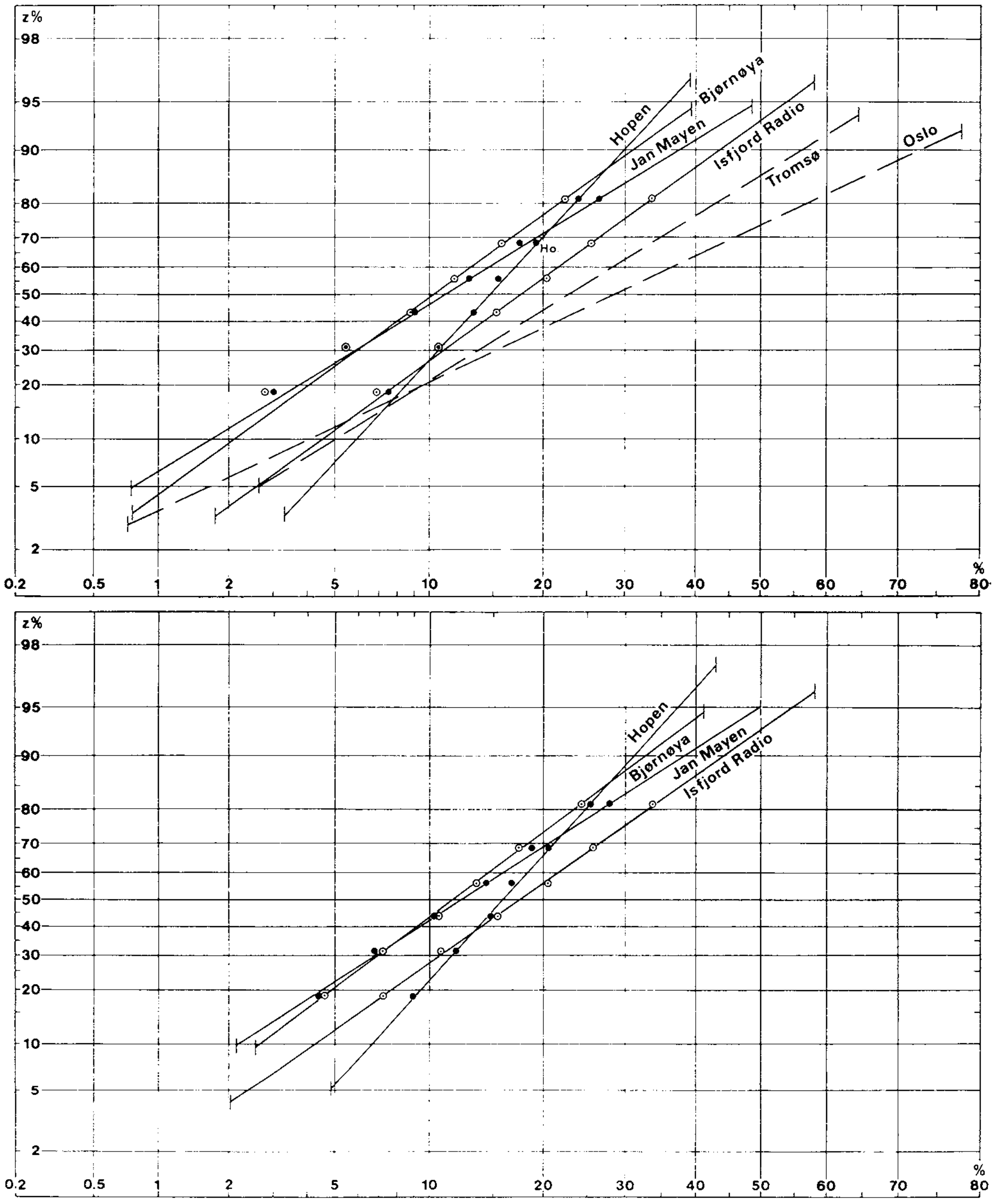


Fig. 2. *Upper part: Cumulative percentage frequencies of cloud amount at 1300 MET for June–August represented in a normal probability diagram. Cloud amount observed in oktas, indicated as percentages (z) along the ordinate. Observation period: 1949–68. Lower part: Identical with upper part, except that 10% of the cases "cloud amount unobtainable" (N = 9) are moved from the class N = 8 to the classes N = 0–1.*

most overcast sky is much more common than in Tromsø and, particularly, in Oslo. These two "low latitude" stations are characterized by comparatively high frequencies of broken cloud covers. Thus, Oslo has the lowest frequency of both totally clear and a totally overcast sky. It can scarcely be doubted that this is the result of a much stronger convective cloud-generating effect during the middle of day in lower latitudes.

As was the case in Fig. 1, the points representing the lowest cloud amounts tend to lie to the left of the straight lines defined by the higher figures on the scale. We have, as previously mentioned, treated N = 9 as equivalent to N = 8. This means e.g. that a shallow Arctic fog with a clear or practically clear sky above, is considered equivalent to a totally overcast sky. Obviously, this is of great consequence for the form of the cloudiness distribution for Arctic stations, where the frequency of fog during the summer season may be very high. During June—August (1949–68) the frequency of N = 9 at noon is 18% at Bjørnøya, 15% at Hopen, 14% at Jan Mayen, and 3% at Isfjord Radio. It is of course difficult to say anything definite about how the cloud amounts above a fog layer are distributed. This distribution is most certainly different from that of the observed cloud amount, probably with relatively more situations with a clear or almost clear sky. We have tentatively moved 10% of the cases of N = 9 to the two lowermost classes: N = 0–1 (i.e. cloud amount less than 15%). The result of this modest replacement is shown in Fig. 2 (lower part). It appears that the points for all stations are now situated very closely along straight lines.

In addition to sampling fluctuations, some of the deviations from strict linearity seem, as mentioned in connection with Fig. 1, to be caused by systematic observation errors, or a predilection for certain scale numbers on the part of several observers. Thus, we find again a suspiciously great frequency of code figure 3, and a correspondingly low frequency in one or both of the classes N = 2 and N = 4.

We then consider the winter months December—February. During most of this period the sun stays below the horizon, the dark season lasting from the end of October to the middle of February at the northernmost station (Isfjord Radio), and from the end of November to the end of January at the southernmost station (Jan Mayen). As it may be very difficult to make reliable estimates of the cloud amount in darkness, the observation material from such periods is no doubt of inferior quality, and systematic errors may easily arise. As revealed by Fig. 3, the distributions for all four stations show the same, systematic deviation from a rectilinear course. As indicated in the diagram, the frequencies of cloud amounts less than, say, 50% tend to follow one straight line, while those exceeding 50% follow another, steeper line. This bend of the distribution curve is most marked for the two northernmost stations. The frequency of N = 9, which is combined with that of N = 8 in the diagram, lies between 4 and 5%, and is thus much smaller than during the summer season. Isfjord Radio is an exception. Here the frequency of N = 9 is as high as 10%. If a certain fraction of these cases is moved to the group N = 0–1, a somewhat more rectilinear course may be obtained (the lower part grows steeper, especially for Bjørnøya and Jan Mayen). However, the result is not so good as when this procedure is applied on the summer distributions.

It should be pointed out that this deviation from linearity is not found in the data for February for Jan Mayen, which is the only one of the stations that

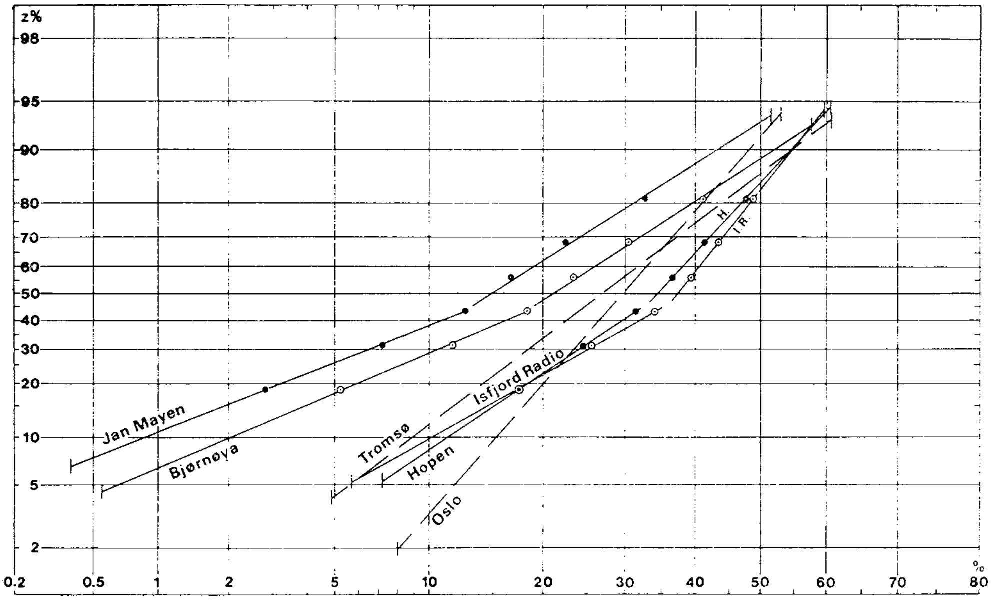


Fig. 3. *Cumulative percentage frequencies of cloud amount at 1300 MET for December–February 1949–68. (Cf. text to upper part of Fig. 2.)*

has the sun above the horizon at noon during the whole of this month. Neither is it found in the winter distribution for Tromsø, where the dark season is nearly as long as at Jan Mayen. In this case the reflection of light from the town by the cloud cover possibly makes the assessment of cloud amount easier. This suggestion obviously involves the assumption that the course of the winter distributions for the Arctic stations "should have been" close to straight lines as well, if only the observation conditions had been good enough. The fact that, in addition to Tromsø, the distributions for the winter months turn out to be practically rectilinear for a series of stations investigated in lower latitudes, lends support to this assumption. One possible reason for the relatively steep course of the upper part of the distribution curves in Fig. 3, might be a tendency to overlook or underestimate openings in the cloud cover during periods of darkness so that N = 8 (or 7) is over-represented in relation to the somewhat lower cloud amounts.

Disregarding these observation problems, Fig. 3 shows that Jan Mayen is distinguished by having the most cloudy weather conditions during winter, followed by Bjørnøya, while Hopen and Isfjord Radio, which have very similar frequency distributions, have a far greater percentage of clear or nearly clear skies.

Annual changes

In Fig. 4 we have for Isfjord Radio and Bjørnøya entered the straight lines from Figs. 2 and 3, indicating the frequency distributions for the summer and winter seasons. The distributions for the month of April is shown as well,

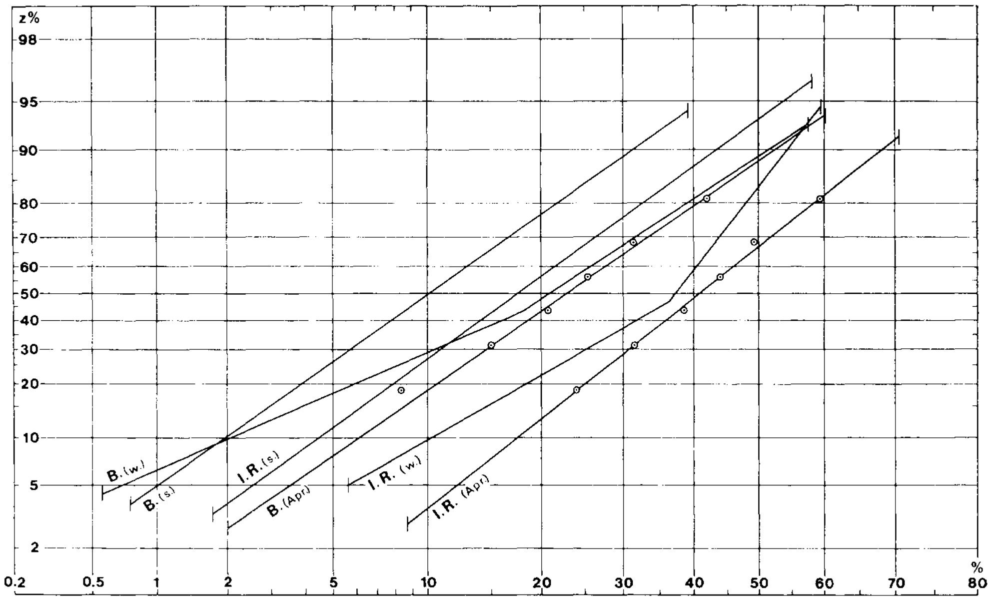


Fig. 4. *Cumulative percentage frequencies of cloud amount at 1300 MET for June–August (s.), December–February (w.), and April. Stations: Isfjord Radio (I.R.) and Bjørnøya (B.). (Cf. text to upper part of Fig. 2.)*

representing the conditions during spring, which normally is the time of the year with the lowest mean cloud amount in these areas, while summer and autumn are characterized by the highest mean cloud amount. The fundamental difference between the cloud conditions during spring and summer is clearly revealed. Thus, at Isfjord Radio the frequency of cloud amounts less than 50% (as read along the straight lines) is 37.6% in April, against 17.6% in June—August. For Bjørnøya the corresponding frequencies are 22.9% and 10.3%. The winter distributions take an intermediate course, lying most close to those of April. We may note that the frequencies of $z<50\%$ are not very different in April and December—February. However, due to the questionable reliability of the winter observations, too much attention should not be paid to the distributions for this season. The diagram gives a clear numerical expression of the fact that spring is the superior season in these regions as far as situations with a clear or predominantly clear sky are concerned. The main reason for this is no doubt that the sea ice has its greatest southward extension during this period, leading to a climate of a more continental character, and a shift of the cyclonic paths towards lower latitudes.

Daily changes

The daily variation of cloudiness is not very great, as indicated by the frequency distributions for Isfjord Radio and Bjørnøya in Fig. 5 (upper part), based on the observations taken at 0700, 1300, and 1900 MET. The corresponding distributions for Oslo are entered for the sake of comparison.

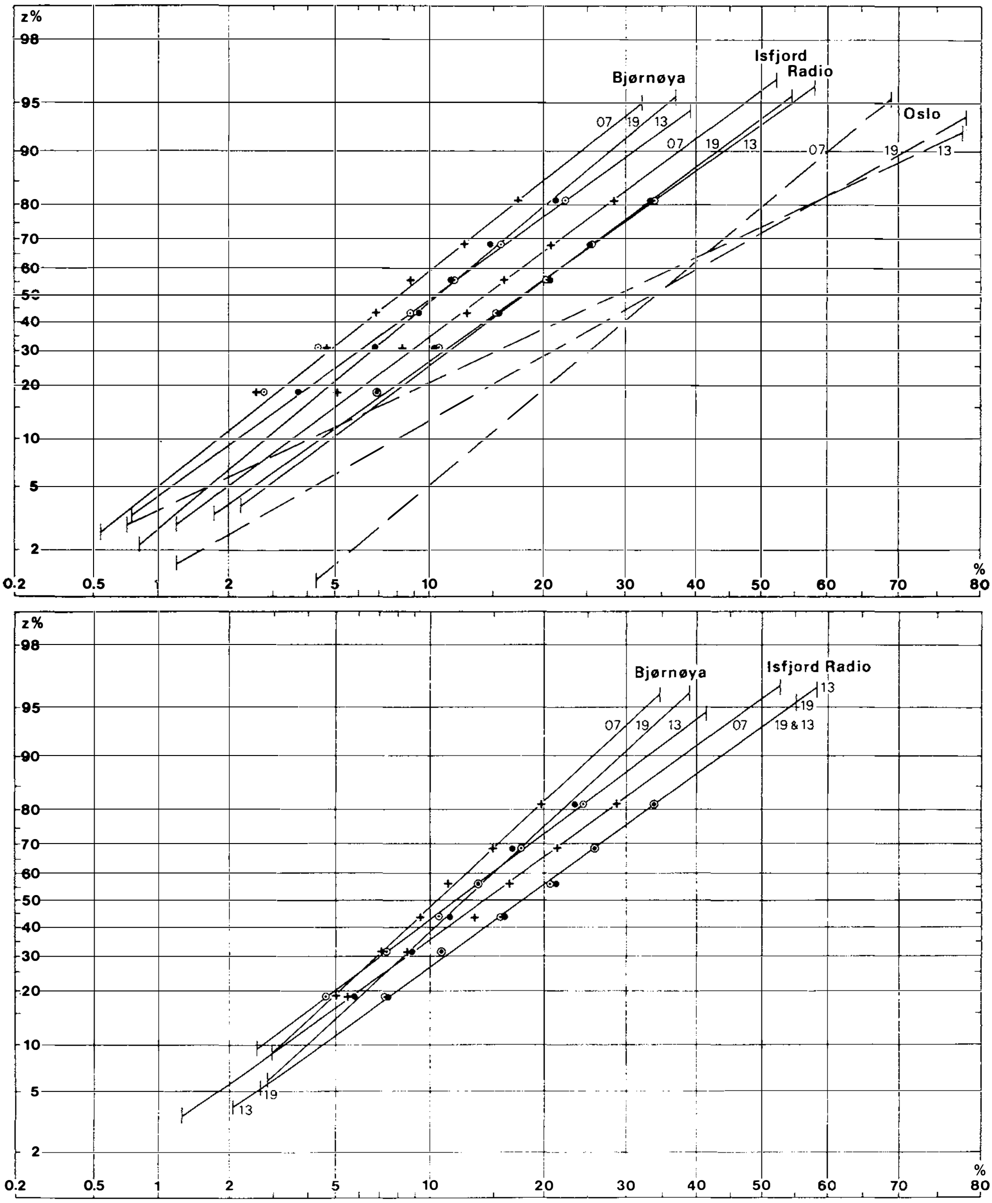


Fig. 5. *Upper part: Cumulative percentage frequencies of cloud amount for various observation hours in June–August. (Cf. text to upper part of Fig. 2.) Lower part: Identical with upper part, except that 10% of the cases "cloud amount unobtainable" are moved from the class N = 8 to the classes N = 0–1.*

The cloudiness is somewhat larger in the morning, and at Bjørnøya the frequencies of a broken cloud cover are slightly greater during the middle of the day. However, this latter tendency is not nearly as pronounced as for Oslo, where the convective effects leave very marked traces in the diurnal course of the cloudiness.

As usual, we have included N = 9 in the class N = 8. If, as was done with the noon distributions before, 10% of the cases of N = 9 are moved to the group N = 0–1, we find again (see Fig. 5, lower part) that the points representing the lowest cloud amounts no longer tend to lie to the left of the straight lines, and that the distributions for all three observation hours now may be described very closely by straight lines. The general features revealed by the upper part of Fig. 5 are not altered, except of course that the distributions are shifted somewhat to the right, especially for Bjørnøya. We note that the "weakness" for code number 3 is again clearly in evidence.

Decennial inequalities

There is a falling tendency of the temperature at the Norwegian Arctic stations from the 1950's to the 1960's. This applies to all seasons, and appears clearly in the 5-year overlapping means, as shown by STEFFENSEN (1969). It may be of interest to see if and how this tendency manifests itself in the cloudiness data.

Fig. 6 (upper part) shows for the summer season the cloud amount distributions for the two 10-year periods 1949–58 and 1959–68 separately. In order not to make the diagram too complicated, only the distributions for Isfjord Radio and Bjørnøya are entered. There is a somewhat greater frequency of an overcast sky (including fog) during the first than during the last period. For Hopen and Jan Mayen, however, the opposite is true. In the case of Jan Mayen small to moderate cloud amounts are relatively more frequent during the last period. For the other three stations the situation is, if anything, the opposite, but the differences are here insignificant. It is thus difficult to find any marked, systematic inequalities between the cloudiness conditions of the two periods as far as the summer season is concerned. It should be added that for this season the above mentioned falling tendency of the temperature is small, as is the variability of the summer temperature in general. The main reason for this fact is easily understood: A clear sky and sunshine is apt to lead to a net radiative heat gain of the ground, and a warming of the surface air, provided the sun is not too low in the sky. An overcast sky, on the other hand, is frequently associated with a cyclonic weather type, and advection of mild air from lower latitudes.

Regarding the winter season, where the long term temperature fall is far more pronounced, Fig. 6 (lower part) reveals that the differences between the two series of years are quite considerable. The typical bend on the winter curves, and the uncertain quality of the observations during this season have been discussed earlier. It can scarcely be doubted, however, that the cloudiness has been far less during the years 1959–68 than during the preceding 10-year period. The distributions for Hopen and Jan Mayen (data not given) show the same systematic features. This corresponds well with the observed temperature fall: Southerly, usually mild winds, are connected with overcast skies, which prevent the heat loss of the ground, and often lead to considerable radiative heat gain. Cold, Arctic air from northerly to easterly direction, on the other hand, is often accompanied by clear or partly clear skies and radiative heat loss

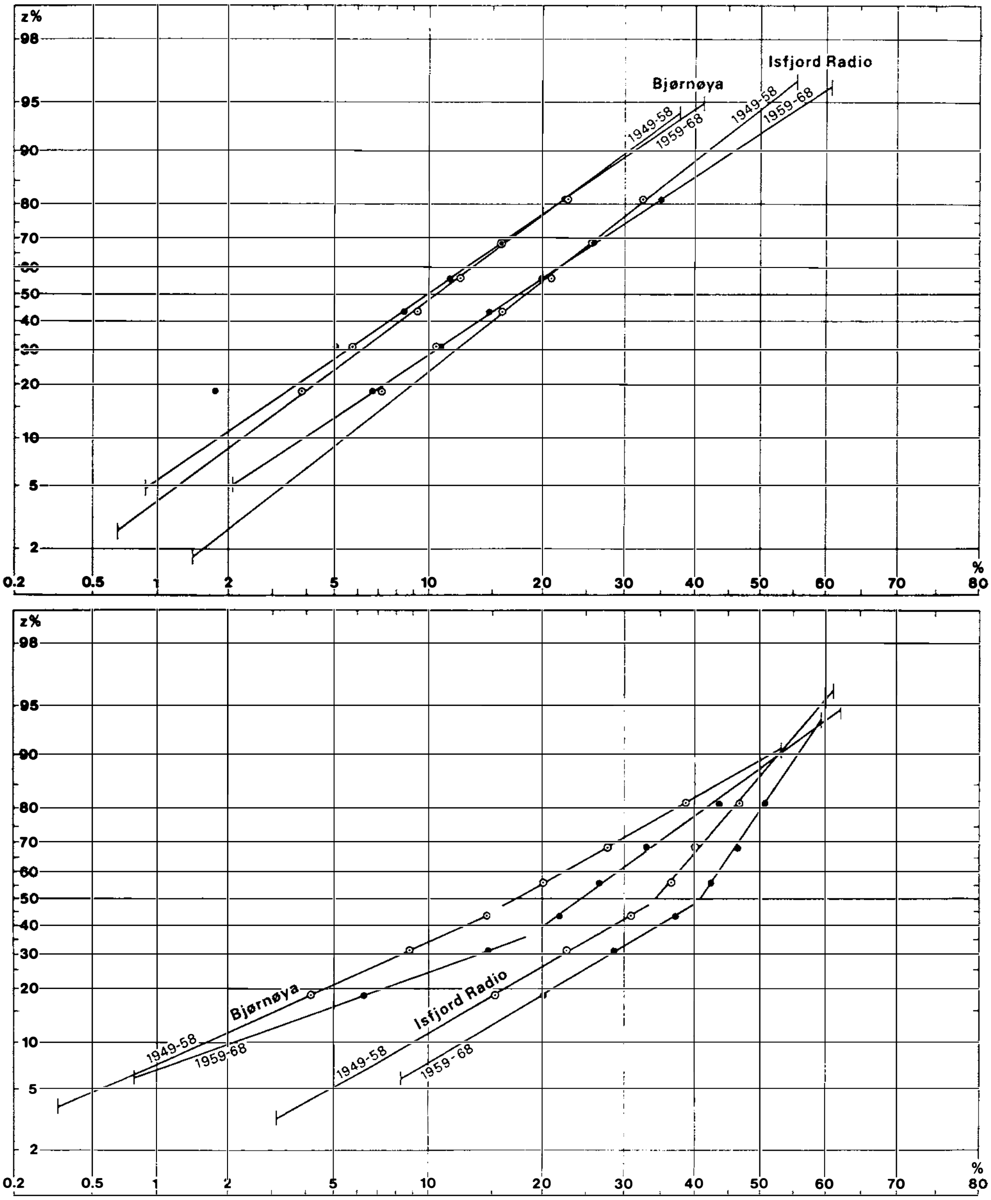


Fig. 6. *Cumulative percentage frequencies of cloud amount at 1300 MET for the two 10-year periods 1949–58 and 1959–68 separately. Upper part: June–August. Lower part: December–February.*

from the ground. The prevailing cloud conditions thus tend to strengthen the advection effect during this season. It goes without saying that the temperature contrast between the two main air streams mentioned above, is considerably more marked in winter than in summer.

Some derived characteristics

The hypothetical distributions represented by straight lines in the probability diagrams may be described by equations of the type:

$$\frac{y - y_{20}}{y_{80} - y_{20}} = \frac{x - x_{20}}{x_{80} - x_{20}}$$

where y is the transformed cloud amount, y_{20} and y_{80} are chosen equal to —1.386 and +1.386 respectively (i.e. the values of y for $z<20\%$ and $z<80\%$), x is the abscissa expressed in standard deviations (of y), and x_{20} and x_{80} the abscissae corresponding to y_{20} and y_{80} respectively. The values of x_{20} and x_{80} may be read along the lines in a large scale diagram. As an example, we have given below the equations of the June—August distributions of the transformed cloud amount at noon, corresponding to the lines in Fig. 2 (upper part):

$$y = 2.89\,x + 2.70 \quad \text{(Isfjord Radio)}$$
$$y = 4.26\,x + 4.49 \quad \text{(Hopen)}$$
$$y = 2.87\,x + 3.64 \quad \text{(Bjørnøya)}$$
$$y = 2.45\,x + 3.02 \quad \text{(Jan Mayen)}$$

From these equations we may, for instance, estimate the upper limit of a certain percentage of the observations. A table of the normal distribution gives the x value corresponding to the percentage in question. The calculated value of y is then easily transformed back to z by means of a table of exponential functions, or an electronic desk computer. Obviously, the opposite procedure gives the frequency of cases below a certain value of z, or in a certain interval of z.

Although, as mentioned previously, the average value is not a very good characteristic of U- (or J-) shaped frequency distributions, climatological descriptions and discussions of cloudiness are, for the sake of simplicity, mainly based on mean cloud amounts. Table 1 (upper part) contains the percentage monthly means, calculated from the observations at 0700, 1300, and 1900MET during the period 1949–68. The minimum during the winter and spring seasons, and the maximum during summer and autumn are clearly apparent. For Jan Mayen the annual change is relatively small.

As shown previously (HISDAL 1974), we may obtain quite good estimates of the mean cloud amount directly from the frequency distributions by using the simple formula:

$$Z = 100 - \tfrac{1}{2}(A + B)$$

where A and B were put equal to the percentages of cloud amounts less than 20% and 80% respectively. In the case of frequencies of daily means, A would correspond to the percentage of so-called "clear days", and (100-B) to the percentage of "cloudy days". (When studying frequencies of individual observations, one might correspondingly speak of clear and cloudy mornings, noons, and evenings.) The formula is based on the following approximations: the

Table 1.

Upper part: Percentage mean monthly and seasonal cloud amounts

Lower part: Percentage mean seasonal cloud amounts for different observation hours (MET) calculated in the ordinary way (under: Calc.), and estimated by means of the hypothetical frequency distributions (under :Est.)

Observation period: 1949–68

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Dec. –Feb.	June –Aug.
Isfjord Radio	59.5	67.9	64.3	58.8	67.5	78.8	81.3	79.5	77.4	75.6	72.9	62.9	63.4	79.8
Hopen	58.9	64.5	59.4	62.8	77.5	82.5	84.6	85.3	87.3	84.9	76.1	68.1	60.9	84.1
Bjørnøya	72.1	76.3	77.1	74.5	83.6	85.9	88.5	88.6	86.6	84.5	82.5	74.5	75.1	87.6
Jan Mayen	79.9	78.3	81.1	81.0	83.6	83.8	85.6	86.1	84.4	86.9	82.4	81.8	79.8	85.1

	Dec.–Feb. 1300		June–August 0700		June–August 1300		June–August 1900	
	Calc.	Est.	Calc.	Est.	Calc.	Est.	Calc.	Est.
Isfjord Radio	65.8	67.0	81.9	83.2	78.5	79.8	78.9	79.8
Hopen	66.7	67.5			83.5	84.1		
Bjørnøya	76.5	77.5	89.3	89.9	86.6	87.2	86.9	87.6
Jan Mayen	81.8	82.9			84.5	85.6		

mean of cloud amounts below 20% is equal to 0% (somewhat too low), that of cloud amounts above 80% is 100% (somewhat too high), while that of the intermediate cloud amounts is put equal to 50%. The accuracy of the formula evidently depends on the extent to which these approximations compensate each other.

In Table 1 (lower part) we have compared seasonal mean cloud amounts for various observation hours. The values under the heading "Calc." are calculated in the ordinary way, while those under "Est." are estimated by introducing in the above formula the frequencies A and B read along the straight lines in Fig. 2 (or they may be found from the equations of the lines). It appears that there is a good agreement between the two sets of means. The estimated values lie systematically 0.6 to 1.3% higher than the calculated ones. This indicates that the somewhat too high mean used for values of z exceeding 80% (the majority of the observations) is not fully compensated for by the too low mean used for z below 20%.

Duration of sunshine

Frequency distributions

For obvious reasons, the relative duration of sunshine is closely connected with the cloudiness conditions. If we assume the mean cloud amount (Z) for a certain period to be a good estimate of the probability that clouds are obscuring the sun, and S is the percentage relative duration of sunshine during that period, the sum (Z + S) should be close to 100%. Evidently, "sunshine" is in this connection a phenomenon that is recorded only when no clouds, sufficiently thick to be "discovered" by the observer, are covering the sun. (The difficult question of defining precisely the limit between "sunshine" and "lack of sunshine" is largely of instrumental nature, and it would lead too far to discuss this problem here. Reference may in this connection be made to works by e.g. WAGNER (1927), BIDER (1958), and SCHIELDRUP PAULSEN (1968).) We shall later consider some of the factors responsible for the well-known fact that the above mentioned ideal conditions are not fulfilled, and that the sum of Z and S generally deviates systematically from 100%.

It has previously been shown for data from Swiss stations (HISDAL 1974) that for daily percentage sunshine (S_d):

$$R_d = \ln \frac{S_d}{100 - S_d}$$

is approximately normally distributed. As is easily seen, this new variable equals the logarithm of the relation between the total time with sunshine and the total time without sunshine during a day, the length of a day being in this connection considered as equal to the maximum possible duration of sunshine on the date considered.

Of the Arctic stations, duration of sunshine has been recorded at Isfjord Radio and Bjørnøya. Frequency distributions of S_d for June—August have been worked out for these stations for the years 1961–70, and, for the purpose of comparison, for Bergen for the years 1965–72, on the basis of data obtained from "Det norske meteorologiske institutt", and from the publication series "Radiation observations in Bergen, Norway" (1965–72). Sunshine recorders of the Campbell-Stokes type have been used. It should be added here that values for individual days of the maximum possible length of a sunshine record are tabulated for Bergen in the latter publication, for Isfjord Radio by SPINNANGR (1968), while for Bjørnøya unpublished values are available at "Det norske meteorologiske institutt".

The distributions are entered in a normal probability diagram with R_d as ordinate (Fig. 7, upper part). We find that the points representing cumulative frequencies of the various percentages of sunshine are, to a fair approximation, situated along straight lines.

The only marked, systematic deviation from linearity seems to be that points representing values of S_d larger than 10%, and still more those representing S_d limits closer to 0% (outside the upper edge of the diagram), lie too far to the left of the straight lines. This indicates that in relation to the hypothetical distributions, represented by the straight lines, the frequency of days with a very small percentage of sunshine is too low compared with the frequency of days with no sunshine at all. On the assumption that the hypothetical distribution applies with good approximation also in this extreme part of the scale, the above mentioned deviation may possibly to some extent be ascribed to overcast days with temporary breaks in the cloud cover. On such days short glimpses of sun may not leave sufficient distinct traces on the instru-

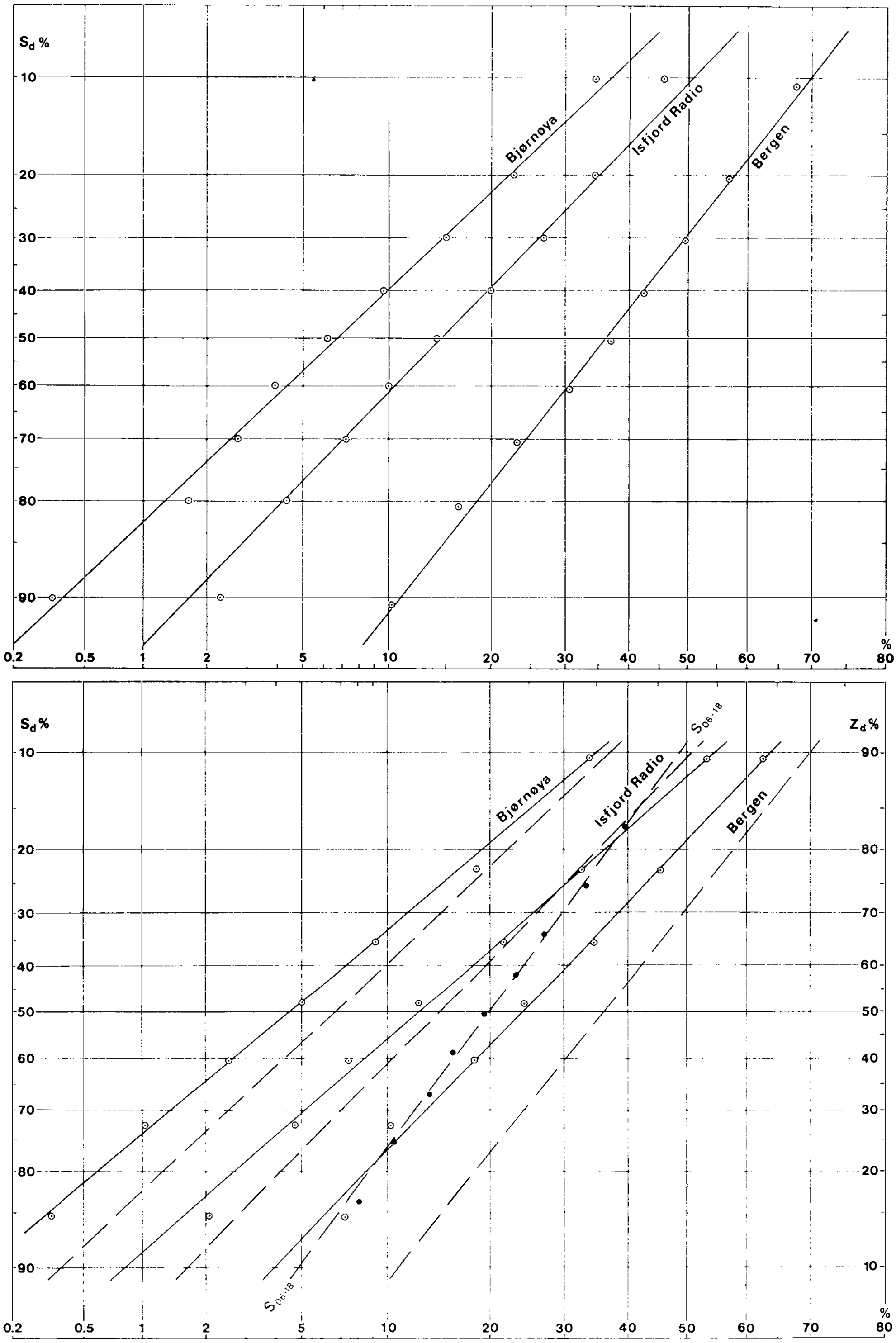


Fig. 7. *Upper part: Cumulative percentage frequencies of daily duration of sunshine* (S_d) *for June–August represented in a normal probability diagram. Observation period for Isfjord Radio and Bjørnøya: 1961–70, for Bergen: 1965–72. Lower part: Comparison between the frequency distributions for the relative duration of sunshine (broken lines) and the corresponding distributions for the daily mean cloud amount,* Z_d *(solid lines).*

Table 2.
Percentage frequencies of days in June—August with relative duration of sunshine (S_d) exceeding certain specified limits

	$S_d > 80\%$ A	$S_d > 50\%$	$S_d > 20\%$ B
Isfjord Radio (1961–70)	4.2	14.5	35.1
Bjørnøya (1961–70)	1.3	6.6	22.2
Bergen (1965–72)	18.2	36.1	58.0

ment cards to be read as "sunshine", especially at low solar altitudes. The extent to which faint traces (recognizable only as changes in the reflectivity of the card) are taken into account, is no doubt of a certain importance in this connection as well. It is difficult, however, to form any definite opinion as to the influence on the frequency distributions of these and other effects (such as the tendency of excessive burning of the Campbell-Stokes recorder) without carrying out special investigations, for instance by means of comparison with measurements made by modern, electronic sunshine recorders.

The diagram illustrates clearly the great difference between the sunshine conditions at the three stations. The frequencies of days with values of S_d exceeding 80%, 50%, and 20%, respectively, as read along the straight lines in the diagram, are shown in Table 2. We note that, for instance, days with $S_d > 80\%$, which we in analogy with the concepts used in cloud amount statistics may call "clear days", are fourteen times as frequent in Bergen as at Bjørnøya, while days with $S_d < 20\%$ ("cloudy days") are nearly twice as great at Bjørnøya as in Bergen, viz. (100–22.2)% against (100–58.0)%.

Some derived characteristics

In the same way as for the cloud amount, the straight lines in Fig. 7 (upper part) may be expressed by equations of the form:

$$R_d = ax + b$$

where x is measured in standard deviations (of R_d). We get:

$$R_d = 2.06\,x + 2.17 \quad \text{(Isfjord Radio)}$$

$$R_d = 1.90\,x + 2.84 \quad \text{(Bjørnøya)}$$

$$R_d = 2.50\,x + 0.88 \quad \text{(Bergen)}$$

By means of these equations we may estimate chosen quantiles of S_d, or the percentage of cases above given values, or between given values of S_d. A short description of the procedure is given previously, when discussing the corresponding equations for the cloud amount.

Table 3.
Percentage duration of sunshine for different months and for the summer season

	Apr.	May	June	July	Aug.	Sept.	June–Aug. Calc.	Est.
Isfjord Radio (1951–60)	43.2	34.1	23.0	20.8	19.4	21.4	21.1	
(1961–70)	40.6	32.5	20.0	19.4	19.2	17.6	19.6	19.7
Bjørnøya (1961–70)	23.5	17.6	14.2	11.0	11.3	11.0	12.2	11.8
Bergen (1965–72)	39.3	38.2	38.6	35.1	39.4	31.7	37.7	38.1

Table 3 contains the percentages of sunshine for individual months during the "light season", as well as for the three summer months combined. We have also entered the values published by SPINNANGR (1968) for Isfjord Radio for the period 1951–60. For all months the percentage of sunshine is somewhat greater during this preceding 10-year period. However, as the corresponding differences in mean monthly cloudiness are relatively much smaller, there may be reasons to suggest that the differences between the two sets of S values for Isfjord Radio are largely due to variations in the sensitivity of the sunshine recorder, or in the evaluation technique. (In fact, information given in the above mentioned publication by SPINNANGR indicates that both influences may have been at work.)

The considerable differences between the stations in Table 3 regarding the sunshine conditions are clearly apparent for all months. In the table two values are given for the summer season. Those entered under "Calc." are the ordinary average values of S_d. The values under "Est." are found on the basis of the frequency distributions in Fig. 6, using a method similar to that applied previously when estimating mean cloud amounts. With corresponding assumptions (i.e. mean percentage of sunshine for all days with $S_d > 80\%$ equals 100%, the mean for all days with $S_d < 20\%$ is equal to 0%, and the mean for all days with $80\% > S_d > 20\%$ is 50%) we obtain the simple formula:

$$S = \tfrac{1}{2}(A + B)$$

where A and B are the percentage frequencies of $S_d > 80\%$ and $S_d > 20\%$ respectively. We see that the agreement between the estimates found by this formula and the ordinary mean values is surprisingly good.

Cloudiness and sunshine

In Fig. 7 (lower part) a comparison is made between the frequency distributions of daily mean cloud amounts (Z_d) and those of S_d. The latter distributions, which are identical with those shown in the upper part of the diagram, are indicated by broken lines. It appears that also the transformed Z_d distributions are roughly rectilinear. (Special characteristics of the distribution of means of samples of a U-shaped population are commented on in another connection (Hisdal 1974).)

We observe that the lowermost part of a Z_d distribution is situated to the left of the corresponding S_d distribution. However, the former distribution is slightly less steep, so that the two lines gradually approach each other as Z_d increases. For Bjørnøya and Bergen the lines do not meet till $Z_d > 95\%$, while for Isfjord Radio they cross each other for Z_d equal to about 75%.

It is well known that for the summer season the sum of the percentage mean cloudiness and the percentage duration of sunshine at stations in lower latitudes tends to exceed 100%. If we assume that, as a whole, one and the same cumulative percentage of data in the diagram contains parts of the Z_d and S_d material that originate from the same group of days, we find that for low to moderate Z_d values, $(Z_d + S_d)$ is considerably greater than 100%, and that this sum decreases for increasing values of Z_d. (Evidently, due to the special way in which the ordinate is divided, this decrease is not linear.)

In order to understand the meteorological basis of these characteristics, it is important to remember that the probability that the sun will burn a track on the instrument card is not independent of the sun's altitude. The probability increases with increasing altitude of the sun. There may be several reasons for this variation, the most important one being presumably that the clouds appear much more packed near the horizon than in the vicinity of zenith ("Kulissenwirkung"). These effects may partly explain why the differnce between the Z_d and S_d distributions (and thus the sum $(Z_d + S_d)$) is by far the greatest in Bergen, where the sun, during a large part of the day, has the largest solar altitude, and passes areas of the sky with an average cloud amount that is smaller than the average for the whole celestial hemisphere.

There is however another important fact that has to be taken into consideration in this connection. As mentioned previously, the daily mean cloud amounts are based on the observations taken at 0700, 1300, and 1900 MET. The Z_d distributions cannot be considered, therefore, as a strictly adequate basis of comparison for the S_d distributions of the two Arctic stations, where the sun is above the horizon day and night during most of the period June—August. In order to demonstrate the significance of this point, we have for Isfjord Radio worked out frequency statistics of percentage sunshine for the 12-hourly period 0600–1800 LAP (denoted S_{06-18}), which is likely to correspond much better to the Z_d distribution given here. As shown in Fig. 7 (lower part) the deviation of this "daytime" distribution of S from the Z_d distribution is much greater than in the case of the ordinary S_d frequencies. It may be mentioned that while the June—August mean of $(Z_d + S_d)$ for Isfjord Radio equals 99% (108% for Bergen), the mean of $(Z_d + S_{06-18})$ is 103%.

The example above is sufficient to illustrate the importance of basing a climatological comparison between cloudiness and relative duration of sunshine on mean cloud amounts that are representative of the period the sun is above the horizon. The great and often unexpected changes of the frequency distributions of Z_d (or S) that may occur when calculating the means from different numbers of daily observations (or S values for different lengths of the day), are due to a combined effect of the persistence tendency of these elements and their U- (or J-) shaped frequency distribution. Unfortunately, a more conclusive study of the relationship between cloudiness and sunshine was hampered by the fact that Z_d values representative of a 24-hourly period were not available for the Arctic stations.

The decreasing value of $(Z_d + S_d)$ when Z_d increases, as revealed by the diagram, is no doubt connected with the fact that the higher the value of Z_d, the greater the probability that it is based on one or more observations of a totally overcast sky. In other words, we approach the situation: $Z_d = 100\%$, $S_d = 0\%$ (disregarding eventual extreme cases where very thin, transparent cloud veils cover the sky).

It may be of interest to find a connection between the frequency distributions of Z_d and S_d, or between corresponding equations of Y_d and R_d. This may give a method of estimating the distribution of S_d for stations where only the cloudiness is observed. With our Z_d values based on observations three times a day we obtain for Isfjord Radio:

$$Y_d = c_1 x + d_1 = 1.76 x + 2.01$$
$$R_d = (1.17 c_1) x + 1.08 d_1$$

for Bjørnøya:

$$Y_d = c_2 x + d_2 = 1.69 x + 2.86$$
$$R_d = (1.12 c_2) x + 0.99 d_2$$

and for Bergen:

$$Y_d = c_3 x + d_3 = 2.07 x + 1.46$$
$$R_d = (1.20 c_3) x + 0.60 d_3$$

The variation from station to station of the relationship between the two equations is not insignificant. Particularly, the coefficient of the d term is much smaller for Bergen than for the two Arctic stations. In all probability, however, this may to a large extent be attributed to the previously discussed fact that the correspondence between the values of Z_d and S_d is not the same (or equally good) for all stations.

Later on, when sufficient relevant data are available, we hope to get an opportunity to return to these questions, as well as to the important problem of estimating frequency distributions of relative global solar radiation by means of cloudiness observations.

Acknowledgement

I am indebted to Mr. H. Schieldrup Paulsen for reading the manuscript and making helpful suggestions.

References

Bider, M., 1958: Über die Genauigkeit der Registrierungen des Sonnenscheinautographen Campbell-Stokes. *Arch.Met.Geoph.Biokl. B*, **9**(2).

Hisdal, V., 1974: A mathematical method for representing frequency distributions of cloud amount and related elements. *Arch.Met.Geoph.Biokl. B*, **22**(3).

Schieldrup Paulsen, H., 1950: On radiation, sunshine, and cloudiness. *Univ. i Bergen. Årbok 1948. Naturv. rekke* (7).

— 1953: Global radiation in Bergen. *Univ.i Bergen. Årbok 1952. Naturv.rekke* (9).

— 1968: A study of the radiation climate of Southern Norway. Part II. *Årbok for Univ. i Bergen 1968. Mat.-Naturv.serie* (2).

Spinnangr, G., 1968: Global radiation and duration ot sunshine in Northern Norway and Spitsbergen. *Met. Ann.* **5**(3).

Steffensen, E., 1969: The climate and its recent variations at the Norwegian Arctic stations. *Met.Ann.* **5**(8).

Wagner, A., 1927: Beziehungen zwischen Sonnenschein und Bewölkung in Wien. *Met.Z.* **44**(5).

On the small scale features of temperature and wind profiles near a snow surface

By Torgny E. Vinje

Contents

Abstract

The profile forms of wind speed and temperature were measured in the lowest meter above a very even, sloping snow surface with the aid of a hot-wire anemometer and a thermo-couple. The sensors were placed on a moving arm which performed one vertical sounding in 25 seconds. Special zigzag features are found in the profile forms close to the surface, during conditions with a gradient flow. Compared with other measurements, it is found that the vertical extension of the zigzag form is reduced markedly with decreasing roughness of the underlying surface. Within the lowest meter, the average profiles are observed to be nonlogarithmic. Some turbulent characteristics have been evaluated, giving some indication of the vertical dimension of turbulent elements and displacements.

Introduction

With the intention of studying the small scale features of profiles and turbulence near a snow surface, a pilot study was made at Camp Norway II, 72°15′S —15′W, during December 1970 and January 1971. Of special interest was the zigzag form in the profiles observed near the surface as reported by Lister et al. (1961), Caisley et al. (1963), and Vinje (1964). Previous measurements indicated that the vertical extension of the zigzag form would decrease with decreasing roughness of the surface. In this respect the present measurements are consistent.

The surface

The observation site was on a slope of 1:22, with a downslope azimuth towards the north. The surface was eroded by katabatic winds, and in spite of several snow-falls, there was a net transport of snow away from the site during our two-months stay. To get an indication of the roughness, a 2 m long pole was placed horizontally on the surface, and the gap between the pole and the surface was measured at 33 evenly spaced intervals in the nearest 20 m from the observation site — one series towards the south and another series towards the east. The standard deviation of the gaps was found to be 1.1 cm. This means that with respect to the reference level for height indication above the surface or the zero plane level, the corresponding standard deviation should be a fraction of one centimeter.

Instruments

The arrangement of the measuring devices is shown on Fig. 1.

A DISA hot-wire anemometer was mounted with the heated string perpendicularly oriented with respect to the surface at the end of an arm which in in 50 seconds could be moved up and down within the lowest meter with the aid of a motor. At the end of the arm was also mounted a copper-constantan thermo-couple which was shielded with double-walled tinfoil. The top and bottom positions of the sensors were recorded automatically by shortening of the temperature circuit. The recording device was a Leeds & Northrup

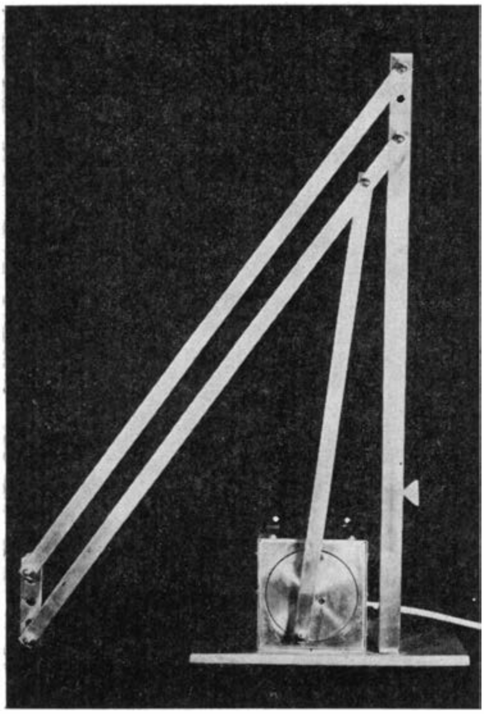


Fig. 1. *The measuring device. The sensor holder (left) was moved over a vertical distance of about one meter in 25 seconds.*

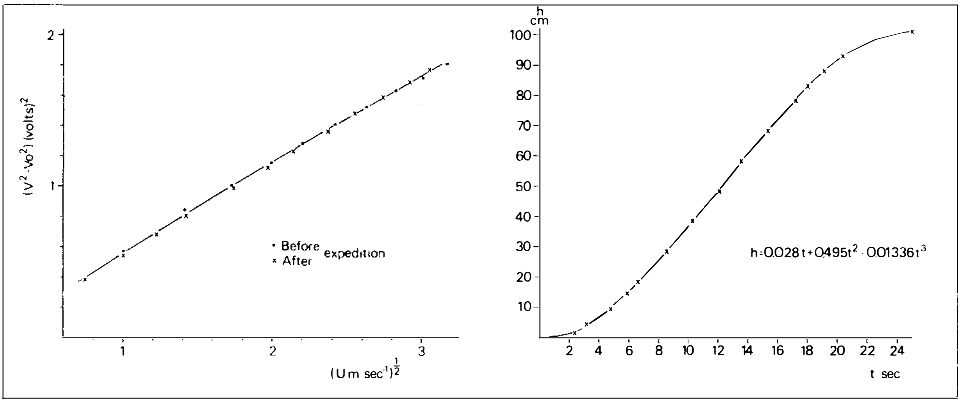


Fig. 2. *Left: Calibration curve for the hot-wire anemometer. Right: Vertical displacement of the sensors with respect to the time elapsed after starting in bottom position.*

Speedomax Recorder, which was placed in an insulated case dug into the snow, the roof being level with the surface to avoid artificial influence on the measurements. The case also provided room for the observer. The temperature inside had to be kept above freezing, and this was managed with the aid of two plastic bottles, 0.2 litre each, filled with hot water and placed in the carefully insulated case every evening. The temperature outside in the snow was about −15°C and inside it was kept at about 5°C by these means.

The hot-wire anemometers were calibrated at the Norwegian Technical University, Trondheim, before and after the expedition. The two series showed only small variations, as was to be expected in view of the very clean air at the observation site. The calibration curve for the hot-wire anemometer used in the field, is given in Fig. 2, left. To the right is shown the relationship between the height of the sensors above the surface with respect to time elapsed after starting in bottom position.

Sources of error

The calibrations of the anemometers were made at sea level air pressure and at +20°C. Camp Norway II was situated at about 1100 m a.s.l. with an ambient temperature of —5, —15°C, and an air pressure of 850–870 mb. Due to this, the density of the air at the observation site would be maximum 10% less than at the calibration site. As we are interested in relative values, a correction for this difference becomes of less interest and has therefore been omitted.

The temperature sensor has a relatively slower reaction compared with that of the anemometer. It was the intention to eliminate this to a certain extent by averaging observations obtained during both up and downward movements of the arm. However, due to a technical deficiency in the device, the measurements from downward movements could not be used, and the height to the points of inflection in the temperature profile are therefore somewhat too high.

From a series of measurements in calm air indoors, it is found that the varying vertical velocity of the sensors, which is maximum 0.6 m sec^{-1}, has no systematic influence upon the vertically orientated string of the hot-wire anemometer.

When the wind speed exceeded 5–6 m sec^{-1}, the snow started to drift and abnormal registrations were recorded when the wind sensor came in contact with snow. The faintest drift was easily observed as its presence was markedly demonstrated by glittering in the sun and by exposure or accumulation on the dark plastic-covered roof of the observation case on a level with the surface. According to these visual controls, it is believed that the wind speed measurements are not effected by drifting snow or floating ice needles.

Examples of registration

Fig. 3 gives some examples of the soundings as they were recorded.

The selected profiles in Fig. 3 show some features which were observed relatively often. It will be seen that a minimum in the wind speed occurs at about 1 to 2 centimeters above the surface, and that a reversed, similar feature occurs in the temperature profiles. It will further be seen that there is some correlation between the variation in the height to the minimum and maximum of wind speed and temperature, respectively. The longest series of consecutive measurements during gradient flow contains 76 single pairs of profiles. In this series, it is found that a minimum in the wind speed, as illustrated in Fig. 3, is observed in 55% of the profiles at an average height of 1.1 cm. For the temperature profiles the corresponding percentage is as high as 82, with an average height of 2.2 cm. Due to the lag of the thermo-couple the latter height should be somewhat reduced. This then brings about a fairly close conformity between the heights to the points of inflection for both temperature and wind speed profiles. It can be mentioned that the above features were not observed during conditions with a katabatic flow. This will be discussed in a later section.

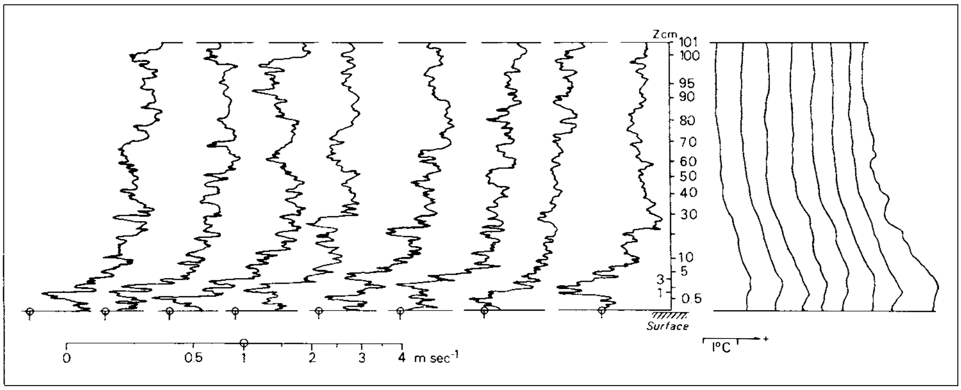


Fig. 3. *Wind and temperature profiles during conditions with positive radiation balance. Start of measurements: 1536 GMT, January 19, 1971. Height from bottom position to surface is 0.5 cm.*

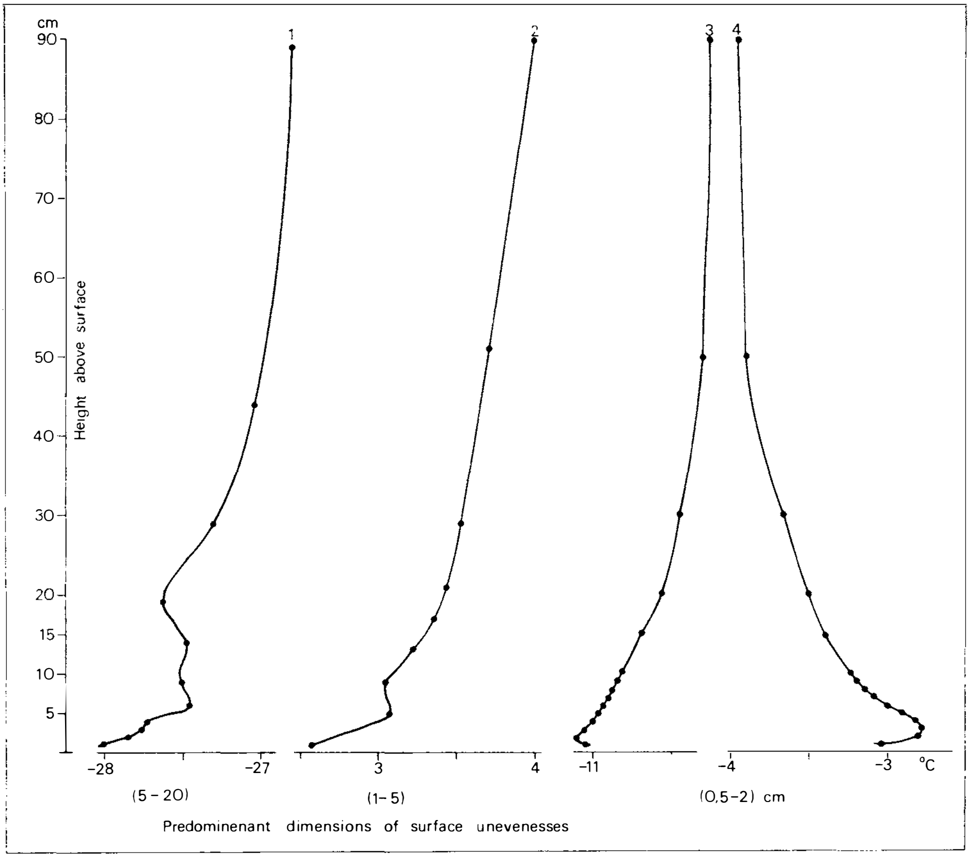


Fig. 4. *Average temperature profiles measured over snow surfaces of different roughness.*

A zigzag profile has been found by CAISLEY et al. (1964) from hourly average values over a glacier. They found, however, the point of inflection at a far greater height, about 20 cm. A similar result was also reported by VINJE (1964) from temperature measurements over an ice shelf, where the standard deviation of surface irregularities was 10 cm. CAISLEY et al. observed both wind speed, temperature and vapour pressure, and they found some similarities, particularly in the distribution of wind speed and temperature.

Fig. 4 gives some temperature profiles observed over snow surfaces of various roughness.

Profile 1) is the average of 16 single observations obtained under various conditions above an Antarctic ice-shelf by VINJE (1964) and profile 2) is the average of 85 profiles measured by the present author over coarse-grained melting snow in Spitsbergen. These profiles were obtained with the aid of thermo-couples at fixed heights. Profiles 3) and 4) show examples of the observations at Camp Norway II, representing conditions with stable and unstable stratification, respectively. For 1), 2), and 3) it is seen that a secondary maximum occurs below a secondary minimum, and compared with 4) it is noticeable that the zigzag form is reversed when the surface changes from being a heat

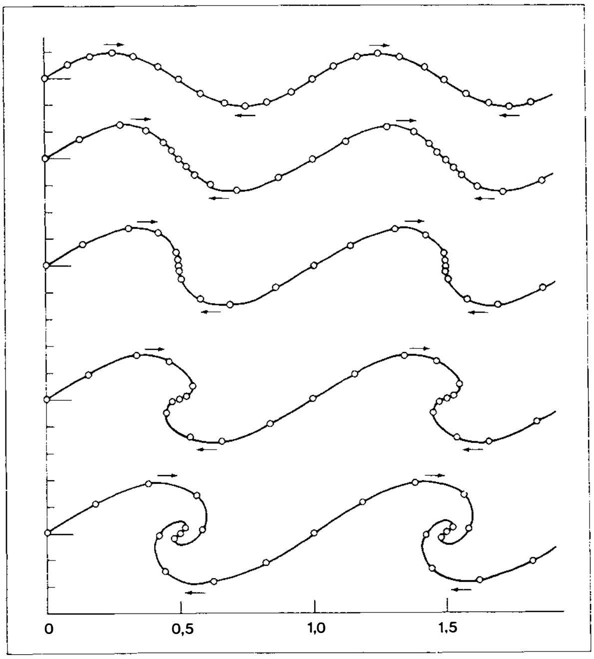


Fig. 5. ROSENHEAD'*s representation of the development of friction vortices.*

sink to being a heat source. Measurements at different places thus indicate that there is a zigzag distribution in the temperature near the surface for average conditions, and that the vertical extension of this special distribution diminishes significantly with a decrease in the roughness of the underlying surface. This suggests that the zigzag profiles referred to here are caused by dynamical processes, and not by processes such as radiative divergence or advection. Theoretical support for this view, as well as a tentative explanation of the phenomenon, may be found in the calculations made by ROSENHEAD (1932). He investigates the flow of a stream of a given density and velocity which flows above a stream of the same density, having the same velocity in the opposite direction. Initially the surface of separation is of the form of a sine-curve of small amplitude. The calculations show that there will be a concentration of vorticity at equal intervals along the surface, and that the surface of discontinuity tends to roll up round these points of concentration. The development is shown in Fig. 5, which is a simplified reproduction of one of ROSENHEAD's figures.

According to this model, it may be supposed that friction vortices are formed close to the surface, and as they must be guided by the underlying ground, the passing of vortices of a predominant dimension formed over a uniform surface may then cause the kind of zigzag form in the average profiles which has been observed. Of special importance is the indication that the surface vortices over a not too smooth ground are of a measurable vertical dimension, several orders of magnitude greater than the socalled roughness length.

Average profiles

For every single sounding the wind speed and temperature have been calculated at all maxima and minima (turning points) in the registration. Values for every centimeter have then been obtained by linear interpolation. Some examples of average profiles for different wind speeds with a gradient flow are represented in Fig. 6. For profiles with a super-adiabatic stratification, the scale of the abscissa for the temperature profiles is reversed. This is marked with an arrow in the respective graphs.

Due to the relatively great lag of the temperature sensor, the corresponding profiles are considerably smoother than the wind speed profiles, and it can be seen that the latter are not completely smooth even for the series which contains the highest number of soundings (profile A).

The point of inflection near the surface is, for the same reason, only retained in the temperature profiles, as can be seen. The height to the corresponding

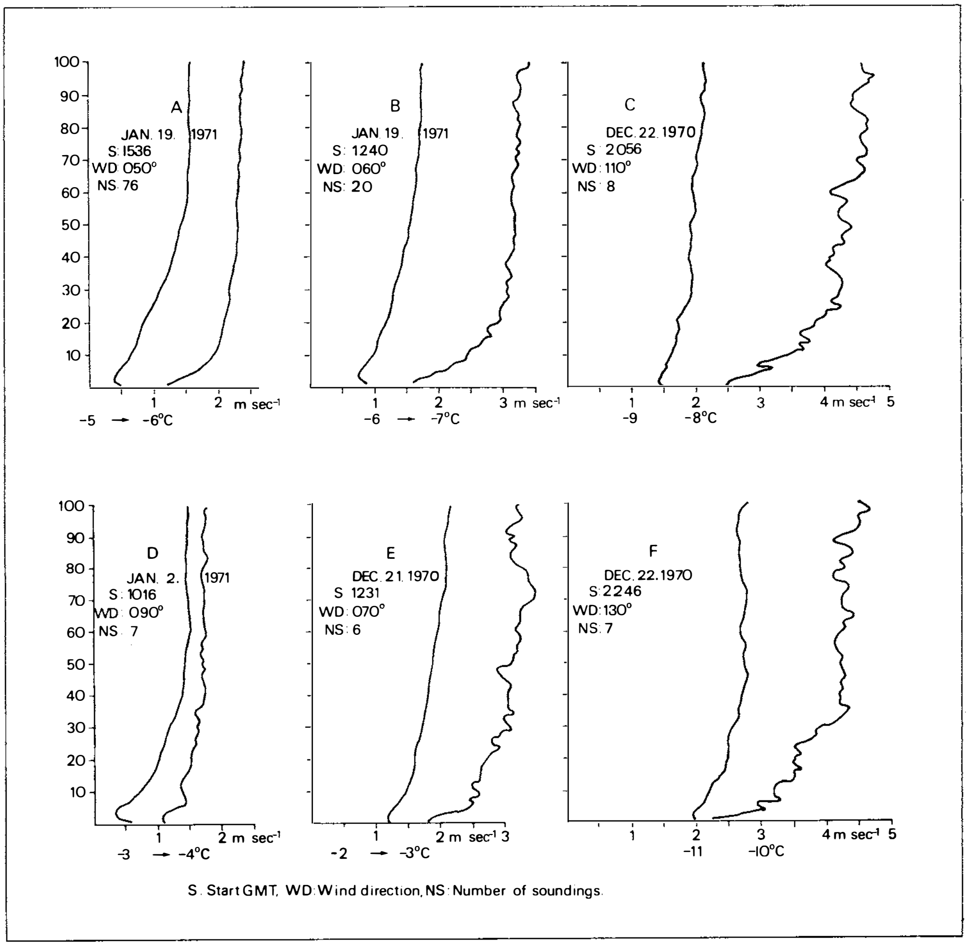


Fig. 6. *Average temperature (left) and wind speed profiles. Positive radiation balance for A, B, D, and E. Note the reversal of the temperature scale. Negative radiation balance for C and F.*

point found in many single wind speed soundings is too small (1–2 cm, cf. Fig. 3) to be retained in the average profiles as the lowest height of interpolation is of the same order, namely one centimeter. An awareness of the dimensional difficulties encountered here is of importance in a further study of the special irregularities of profiles near the surface.

The reference level for the height measurements above a surface should be a socalled zero-plane level which necessarily must intersect the unevenesses on the surface. The zero-plane level was not determined for the present measurements, so a small uncertainty, say $\pm < 1$ cm (cf. p. 28), exists as to the precise information on the height above this reference level. In spite of this uncertainty, it can be seen that the wind speed at the lowest levels is observed to be relatively high. This is in accordance with the fact that the snow drift is observed to have a considerable speed along the undulations on the surface, i.e. above as well as *below* the zero-plane level. These considerations throw some doubt upon the concept of no slipping at the reference level. If also the turbulent exchange mechanism or vortices near the surface have a vertical dimension as indicated in the former section, it might not be physically well founded to integrate profile equations to the height corresponding to the socalled roughness length. The vertical dimension of the surface vortices should in this connection be taken into account when determining the lower level of integration.

Of special interest is the indication (Fig. 6) that the vertical height to the point of inflection, or tentatively, the dimension of the vortices decreases with wind speed and increasing stability. It is known that an increase in wind speed will increase the vertical turbulent displacements and that an increase in stability will subdue these movements. The observations thus indicate that the thermal influence on the turbulence is effective very close to the surface. This influence is also illustrated in Fig. 7. The figure indicates that in spite of a considerable increase in the wind speed, the accompanying decrease in the instability probably has the effect that there is no marked increase in the vertical dimension of the surface vortices.

Fig. 8 shows some wind speed profiles in a semi-logarithmic diagram, representing observations A, B, and C in Fig. 6, which have been smoothed out visually. The logarithmic profile form is seen to tally poorly with the observations within the lowest meter above this sloping snow surface. The form of the curvature below 10 cm again indicates a relatively high wind speed near the

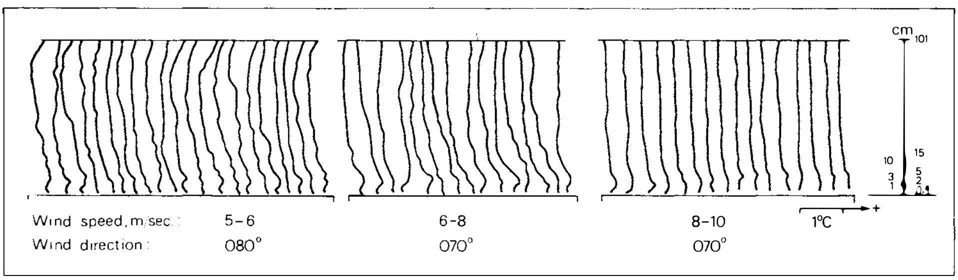


Fig. 7. *Temperature profiles obtained during conditions with relatively high wind speed and drifting snow.*

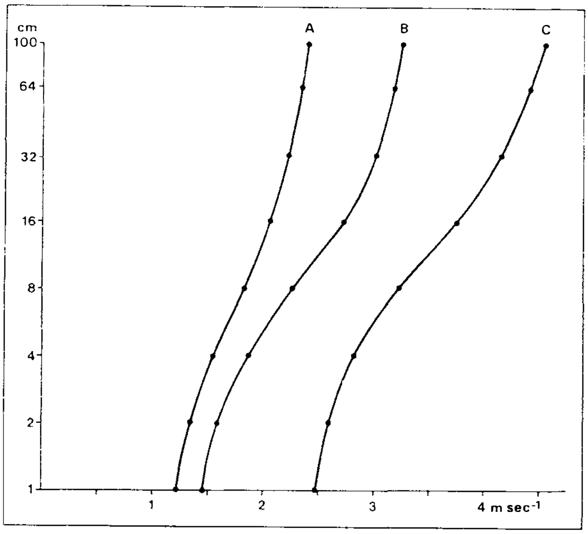


Fig. 8. *Average smoothed wind speed profiles in a semi-logarithmic diagram representing observations given in A, B, and C in Fig. 6.*

surface. It is noticeable that the profiles are very similar both for stable and unstable temperature stratification. This might possibly be expected so close to the surface where the dynamic turbulence is supposed to be of dominant importance for the profile form.

Profiles in katabatic flow

On the slope at Camp Norway II the katabatic winds were predominant when the net radiation became negative and the gradient wind was weak. In Fig. 9 are reproduced some registrations obtained in a very shallow katabatic flow which developed on a calm afternoon. The figure indicates that the thickness of the flow is less than one meter for some of the soundings. We note also the regular turbulent activity near the surface and the marked decrease in disturbancies with height. (Cf. also Fig. 3 for comparison of turbulent motions.) This indicates that there is a relatively small turbulent exchange between the katabatic flow and the overlying air. At this early stage of the phenomenon, there were relatively strong mirages, and against the horizon wavelets could be seen travelling at some distance from the surface. Some indications of this phenomenon is possibly revealed in the registrations reproduced in Fig. 9. One can see more regular variations in wind speed and temperature in some of the traces at upper levels. Waves in connection with very stable stratifications in the atmosphere have been reported by e.g. LILJEQUIST (1957), VINJE (1964), and HOLMGREN (1972).

From Fig. 9 it is also apparent that the greatest increase in temperature with height seems to correspond with a decrease in the wind speed. Such a correspondence is also suggested by HOLMGREN (1971) from measurements in gravity flow of greater thickness.

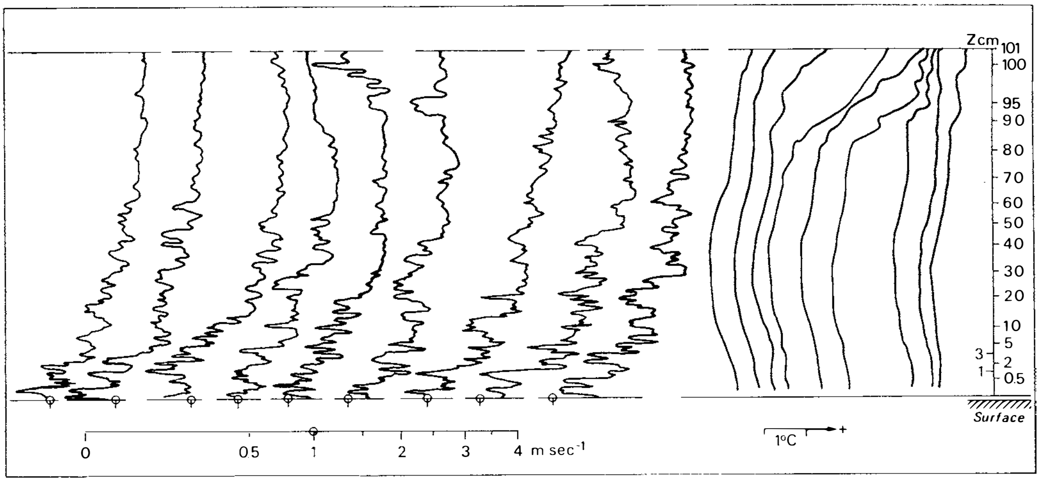


Fig. 9. *Observations of consecutive wind speed and temperature profiles during conditions with a katabatic flow. Start of series: 1912 GMT on January 8, 1971. Height from bottom position to surface is 0.8 cm.*

Due to the observed marked reduction of the turbulence with height the mechanism for the development of a thermocline may, tentatively, be as follows: A relatively great temperature gradient is built up at some distance from the surface when a katabatic flow has arisen. The turbulent heat exchange in the separation area is then so substantially reduced that the stability in this area will be further increased, and a thermocline may be developed, as the temperature in the katabatic flow below decreases further. The appearance of thermoclines over a sloping terrain has been observed and discussed by HOLMGREN (1971). He points out that it is difficult to understand the existence of such features if the turbulent exchange is not substantially reduced across the layer of the steep lapse rate. In this respect the present observations support his suggestion.

Fig. 10 shows some average profiles of katabatic flow. The profile marked G is the average of those shown in Fig. 9, and H refers to the consecutive measurements. As can be seen, the temperature profiles for katabatic flow differ noticeably from those observed during gradient flow (cf. Fig. 6). No point of inflection near the surface is observed, and there is a super-adiabatic stratification near the surface with an inversion above. This is particularly pronounced for the very shallow flows, represented by G and H. The form of the temperature profile close to the surface shows that the effect of the advection of colder air in these cases dominates over the effect of the radiation loss from the surface.

On the variation of the turbulent motions with height

To obtain the frequency of the variations in the wind speed, regardless of magnitude, all pairs of consecutive maxima and minima (turning points) on the traces of registrations (cf. e.g. Fig. 3) have been counted within intervals of 10

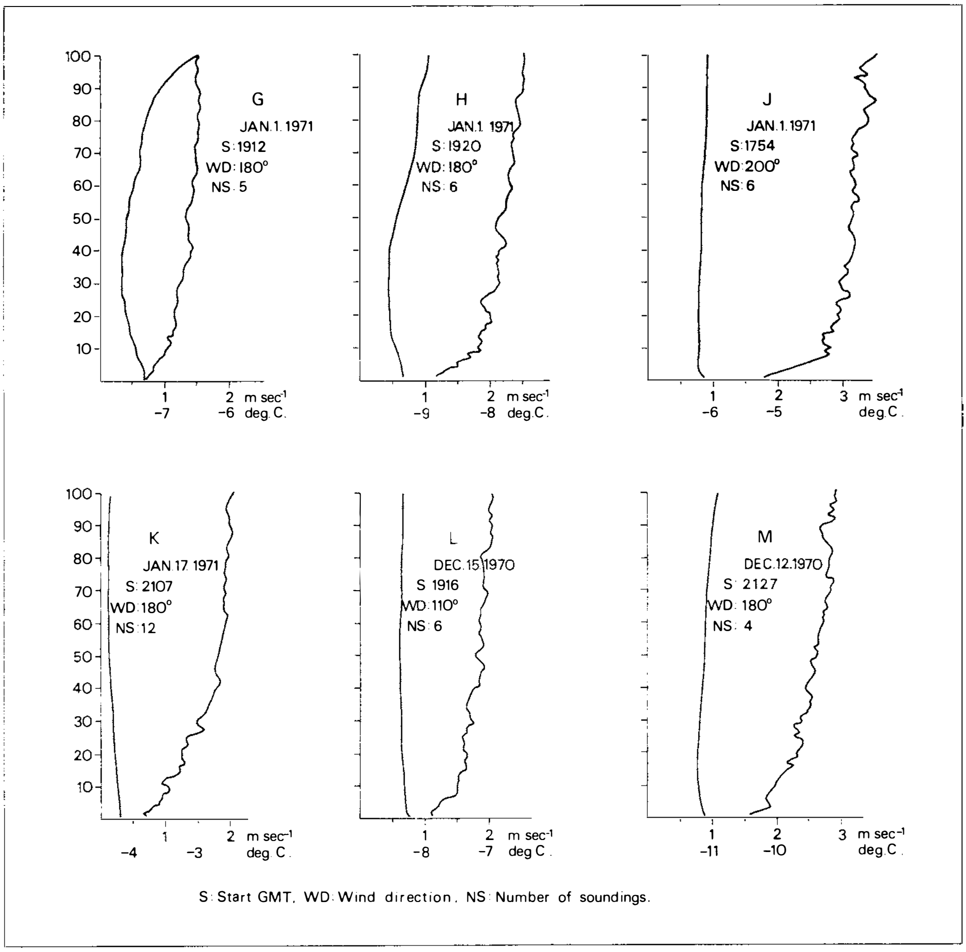


Fig. 10. *Average wind speed (right) and temperature profiles during katabatic flow. Profiles G represent observations given in Fig. 9.*

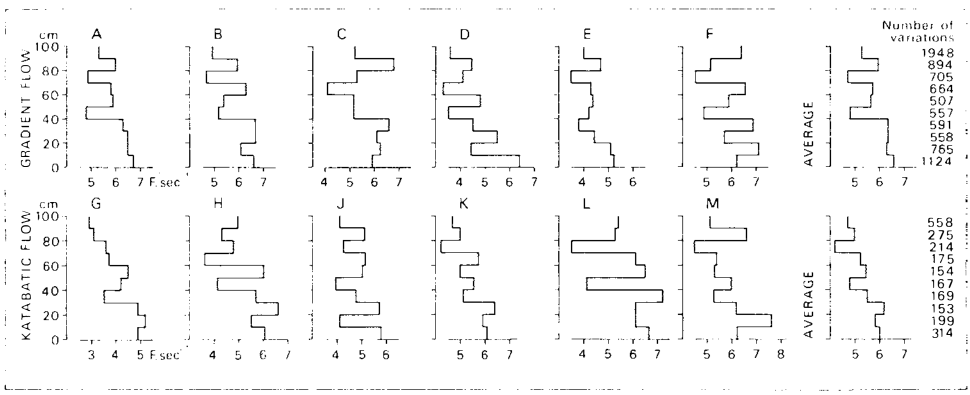


Fig.11. *Frequency of variations in the wind speed with respect to height.*

cm. The calculated frequency represents accordingly the number of variations observed, divided by the time it takes for the anemometer to move over a vertical distance of 10 cm. The obtained frequency (F sec^{-1}) for the series represented in Figs. 6 and 10, is given in Fig. 11, together with the averages. It is seen that we do not get a monotonical decrease with height of F as was expected. The graphs give the impression of alternating maxima and minima in the intensity of turbulent motions with respect to height. This zig-zag distribution which is most frequently observed at upper levels, is somewhat reduced when considering the average values, but even here the feature is pronounced in the upper half of the graphs. In this respect, there is no significant difference between katabatic and gradient flow.

This feature might possibly indicate a guiding influence of the surface upon the turbulent pattern. If the intensity of the turbulence has a tendency to be "stratified", the thickness of layers of extremum should presumably depend upon the predominant dimension of the turbulent eddies at the corresponding height. As has been seen previously, p. 30, the surface vortices may be of the order of one centimeter above the relatively flat terrain at Camp Norway II, and an interval length of 10 cm is then too wide to disclose a possible zigzag feature near the surface so pronouncedly as observed at higher levels.

The above discussion is based on observations obtained by moving the anemometer vertically. Some results from observations at fixed heights around 0.5, 40, and 100 cm above the surface will be given below. Of particular interest in the present context is the frequency distribution of the difference in the wind speed between consecutive maximum and minimum observations, here denoted by $\triangle U$. The frequency distribution of $\triangle U$ is shown in Fig. 12. It is seen that the maximum frequency of both the modes becomes better defined when approaching the surface. This is plausible from the concept that friction vortices of a predominant dimension repetitively pass under an increased steering influence when approaching the underlying ground.

At the lowest height it can be seen that the most frequent variations are about $\pm$ 0.2 m sec^{-1}. This corresponds to a vertical displacement of one to two centimeters according to profile A, Fig. 8. This is in fair accordance with the

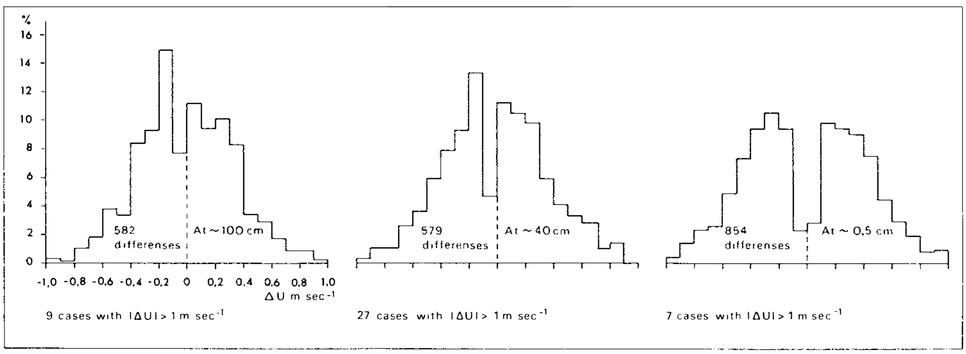


Fig. 12. *Frequency distribution of the magnitude of variations in the wind speed at about 0.5, 40, and 100 cm above the snow surface.*

height of a minimum in the wind speed, which is observed relatively frequently (p. 30).

From Fig. 12 it can also be seen that the most frequent negative variations are somewhat better defined than the most frequent positive ones, especially for the two upper heights. This may be a result of the fact that the turbulent motions are initiated from below. The corresponding compensating movement from above could then be expected to cause variations within a broader scale.

Summary

Observed zigzag profiles near the surface show accordance with the expected vertical temperature and wind speed distribution in the friction vortices calculated, on a theoretical basis, by ROSENHEAD (1932). Measurements at different places over snow surfaces indicate that the vertical dimension of these eddies decreases significantly with increasing smoothness of the underlying ground. The thermal influence on the turbulence seems to be effective also close to the surface. The vertical extension of the surface vortices can be compared with the dimension of the average unevenesses on the surface, and is thus several orders of magnitude greater than the socalled roughness length. This may thus, tentatively, give rise to questions about a physically founded, lower integration height of profile equations over an aerodynamic snow surface.

Acknowledgements

The author wants to thank The National Science Foundation for generous aid with the expedition. Thanks are aslo extended to Mr. A. RØDSETH for the calibration of the anemometers as well as for evaluating a temperature correction formula, and to Mr. P. GROTH for the electronic data processing. The author also wishes to acknowledge the assistance of the members of the expedition. Mr. V. HISDAL and Mr. Y. GJESSING read the manuscript and gave helpful suggestions for improvement.

References

CAISLEY, B. et al., 1963: Measurements of profiles of wind speed, temperature and vapour pressure near the ground. *Publ. No. 61 de l'Assoc. Internat. d'Hydrologie Sc.Assem. Gen de Berkeley* 1963. Gentbrugge.

HOLMGREN, B., 1971: Climate and energy exchange on a subpolar ice cap in summer. *Met. Inst. Uppsala Universitet, Meddelande* Nr. 109, Uppsala.

LISTER, H. et al., 1961: Heat balance and ablation on an Arctic glacier. *Meddelelser om Grønland*, **158** (7). København.

ROSENHEAD, L., 1932: The Formation of Vortices from a Surface of Discontinuity. *Proc. Roy. Soc. London.* Series A. **134**. London.

VINJE, T. E., 1964: On the radiation balance and micro-meteorological conditions at Norway Station, Antarctica. *Norsk Polarinst. Skrifter* Nr. 131. Oslo.

Observations on the Upper Palaeozoic stratigraphy of the Ny Friesland area

By ØRNULF LAURITZEN and DAVID WORSLEY[1]

Contents

Abstract

A relatively complete section through the Carboniferous and Permian rocks of Ny Friesland suggests a minimum thickness of approximately 600 metres for this succession. The Nordenskiöldbreen and Gipshuken Formations are characterised by dolomites and minor biomicrites with low clastic contents, while silicified sandy biosparites dominate the Kapp Starostin Formation.

Introduction

The Norsk Polarinstitutt expedition of 1970 spent several days in Lomfjorden. Exposures were examined on Bivrastfonna and along the east coast of the fjord from Mjølnerfjellet to Kantbreen. A section was later measured on the slopes of Eremitten on the eastern side of Hinlopenbreen (Figure 1).

Information on the Upper Palaeozoic stratigraphy of north-eastern Svalbard is limited: CUTBILL (1968) published a general review of the Ny Friesland area, while LOWELL (1968) produced a composite section through the Permian deposits of Nordaustlandet. Several of the field observations presented here augment this previous work, while microfacies analyses carried out on thin sections of the samples collected increase our knowledge of the depositional environments represented in this Upper Palaeozoic succession.

[1] Paleontologisk Museum, Sarsgt. 1, Oslo 5.

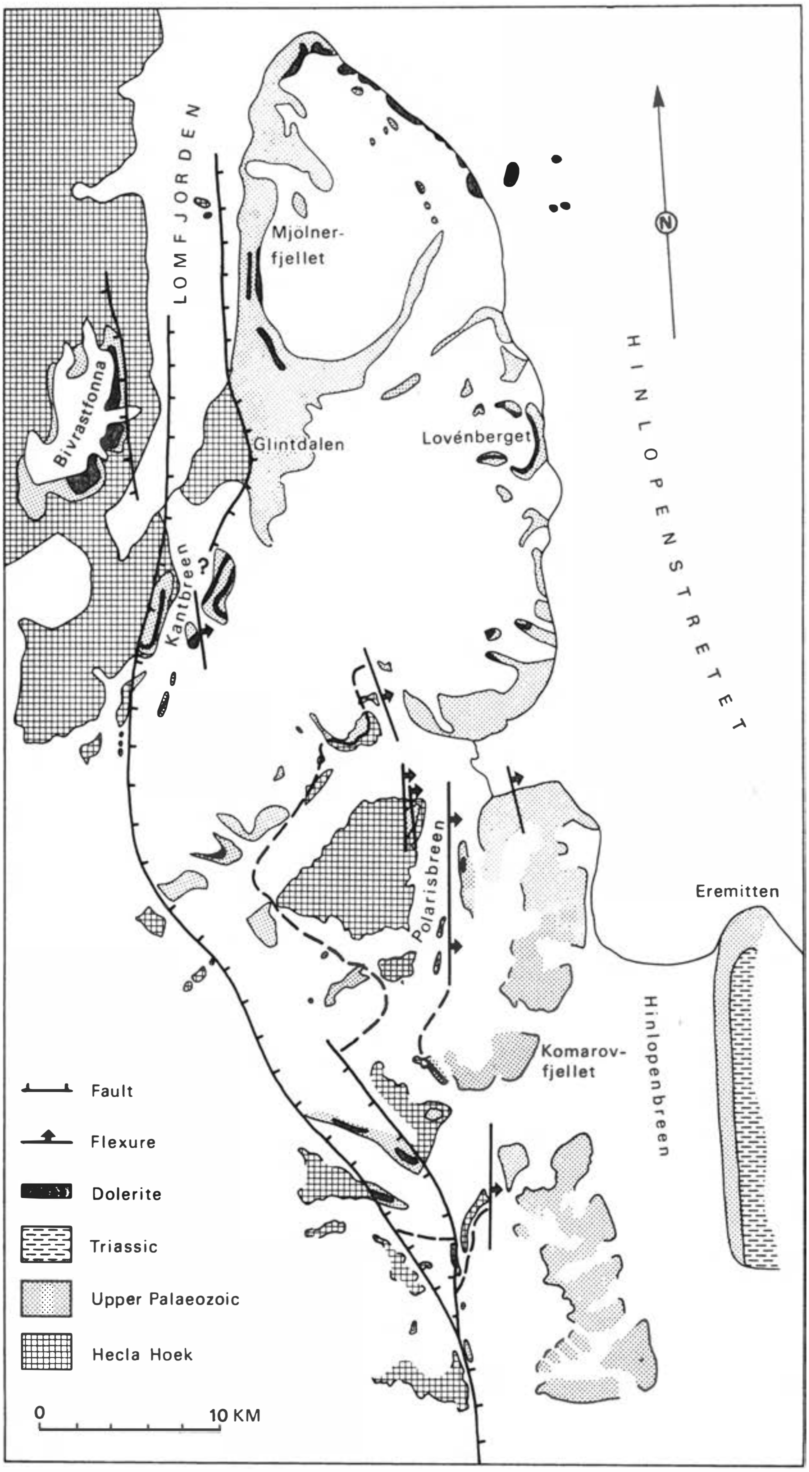


Fig. 1. *Geological map of eastern Ny Friesland; modified after* CUTBILL (1968).

Stratigraphy

The outcrops studied are assigned to the units defined by CUTBILL & CHALLINOR (1965). CUTBILL (1968) suggested that the Ebbadalen Formation was overlapped eastwards from Billefjorden by the younger formations.

Formations seen with approximate ages:

Kapp Starostin Formation:	Kungurian + Upper Permian
Gipshuken Formation:	Artinskian
Nordenskiöldbreen Formation	
(III) Tyrrellfjellet Member:	Asselian + Sakmarian
(II) Cadellfjellet Member:	Gzhelian
(I) Minkinfjellet Member:	Upper Moscovian

? break in sedimentation (Ebbadalen Formation in Billefjorden trough)

Svenbreen Formation:	? Viséan – Namurian

SVENBREEN FORMATION

KULLING (1934, p. 212) described a series of coarse sandstones and conglomerates on Bivrastfonna to the west of Lomfjorden. These beds were assigned by CUTBILL (1968) to the Svenbreen Formation. Measurements made in 1970 indicate a minimum thickness of 100 metres for these sandstones; this is apparently much greater than the thickness observed by CUTBILL further south in Ny Friesland (Fig. 1), although CUTBILL's placing of the overlying Nordenskiöldbreen Formation's base is debatable. This is especially seen on Malte Brunfjellet (100 km south of Lomfjorden); CUTBILL (1968, Fig. 6) here shows 28 metres of sandstones and 69 metres of unexposed limestones at the base of Carboniferous succession, and he assigns all of these beds to the Nordenskiöldbreen Formation. WINSNES (1966, Fig. 4, and pers. comm.) had in fact found 95 metres of basal sandstones and it seems probable that these should all be assigned to the Svenbreen Formation. Thus it is suggested that the Svenbreen Formation is thicker than previously assumed in this area.

Several workers have also noted exposures of the Svenbreen Formation on the east coast of Lomfjorden; these apparently outcrop to the north of the area studied in 1970. CUTBILL (1968, Fig. 2) suggested that this formation occurs along the coast southwards to Glintdalen (Fig. 1), where it rests unconformably upon the Hecla Hoek. This suggestion is not supported by our investigations: because of a gentle southerly dip, the basal limestones of the Nordenskiöldbreen Formation occur at approximately 150 metres above sea-level on Mjølnerfjellet, but outcrop at sea-level immediately north of the junction with the Hecla Hoek. This would rather support a faulted junction, as suggested by the geological map of ORVIN (1940). Observations by KULLING (1934) in the same area support this conclusion.

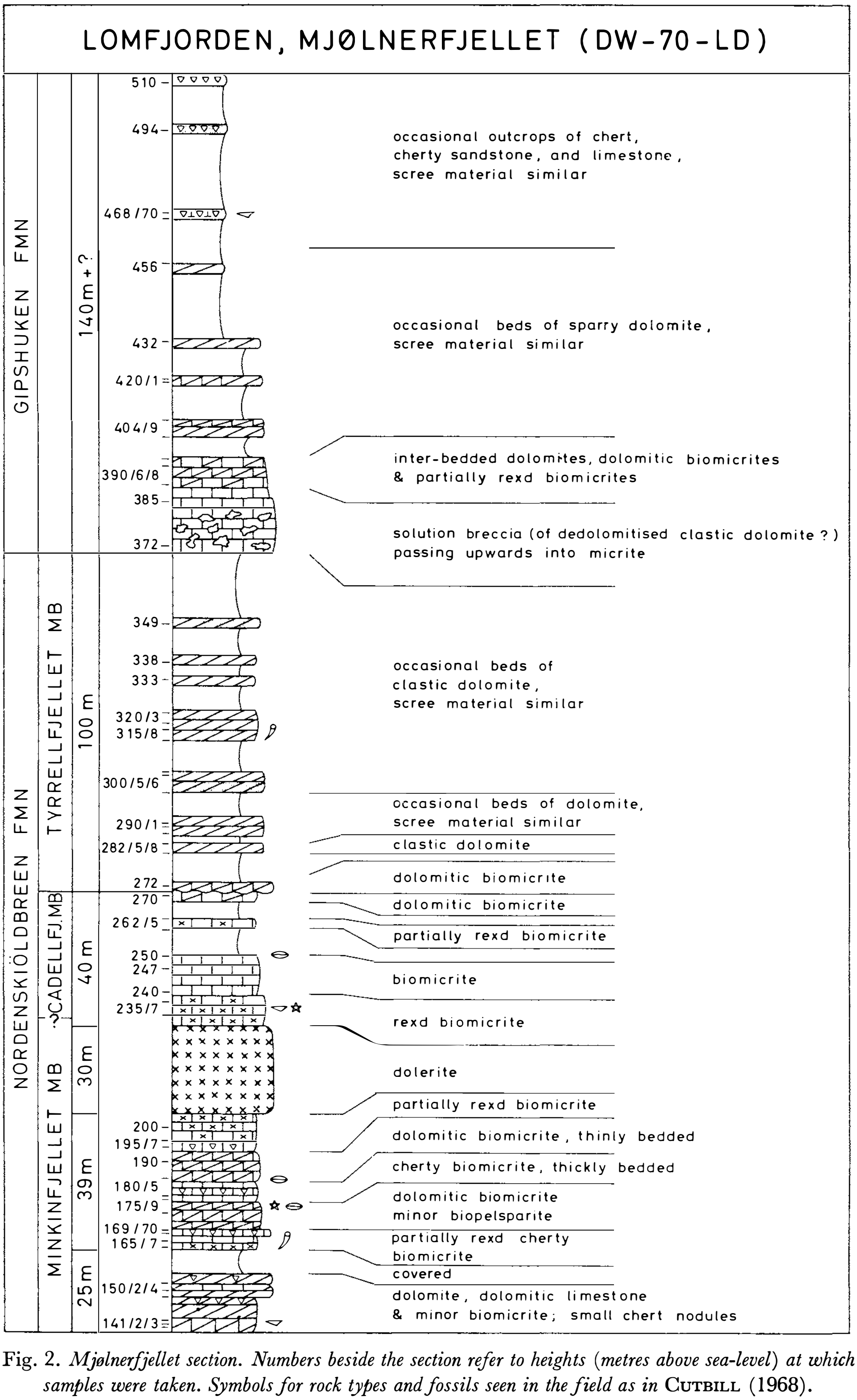


Fig. 2. *Mjølnerfjellet section. Numbers beside the section refer to heights (metres above sea-level) at which samples were taken. Symbols for rock types and fossils seen in the field as in* CUTBILL (1968).

NORDENSKIÖLDBREEN FORMATION

This and the overlying Gipshuken Formation outcrop on Mjølnerfjellet (see Fig. 2 and Table 1), although exposure becomes poor upwards and the succession is intruded by dolerite sills. The lowermost beds found consist of dolomites and dolomitic limestones; dolomite rhombs show a marked zonar development and occasional limestone patches between the rhombs consist of coarsely crystalline calcite. These beds are overlain by cliff-forming biomicrites with interbedded dolomitic limestones; the whole of this succession (approximately 105 metres thick) is assigned to the Minkinfjellet and Cadellfjellet Members, although the exact junction between these members (based on fusulinids, see CUTBILL 1968, p. 14) is obscured by contact metamorphism. The succession has a low terrigenous content (mean 5.1%); this consists equally of clay and silt-size quartz. The bioclastic content is highly variable, but is dominated by echinoderm, brachiopod and fusulinid débris; pellets are rarely seen. Where partial dolomitisation has occurred it is apparent that the original biomicrites have been recrystallized to sparry calcite prior to dolomitisation.

The junction between the Cadellfjellet Member and the Tyrrellfjellet Member is placed at an erosive contact above which the succession consists entirely of dolomites. Most of these appear to be clastic dolomites, i.e. they result from the erosion and redeposition of sediments subjected to early diagenetic dolomitisation. Thus clastic grains of dolomite, many of which now consist of fossil débris ghosts, occur in a dolomite mud matrix. Clastic dolomites containing oolite ghosts are also seen occasionally. The terrigenous content of this member is similar to that of the underlying succession (mean 4.9%).

GIPSHUKEN FORMATION

A disjointed cliff-line marks the base of this formation on Mjølnerfjellet. The basal unit (16 metres thick) consists of a limestone breccia; angular clasts occur in a finely crystalline matrix which is slightly richer in quartz than the clasts themselves; beds of micrite become more common upwards. Relict and ghost dolomite rhombs suggest that this unit represents a brecciated dolomite which has subsequently been dedolomitised. Similar limestone breccias were recorded by CUTBILL (1968) in Ny Friesland as far south as Kvitbreen. However these appear to have highly variable thicknesses, as from neighbouring localities on Polarisbreen GOBBETT (1964) records a 60 metre thick breccia while CUTBILL (1968) records a 34 metre thick micrite unit with breccia only in its lowermost parts.

The succession above this basal unit is again dominated by dolomites (see Fig. 2 and Table 2), although exposure is very poor on Mjølnerfjellet. Silicified material becomes more common upwards in the succession, and the highest points of Mjølnerfjellet are covered by screes of chert and silicified calcareous sandstones. The dolomites of this formation differ both from the clastic dolo-

Table 1

Microfacies analyses of samples from the Nordenskiöldbreen Formation on Mjølnerfjellet. Abbreviations: dm (dolomite), qz (quartz), ech (echinoderm), bra (brachiopod), I.R. (insoluble residue). Dolomite crystal- and grain-size based on Leighton *and* Pendexter *(1961), i.e. crypto-, micro-, very fine, fine, and medium grained/crystalline. + denotes minor occurrences of components. Numbers in brackets indicate interpreted primary content prior to recrystallisation and/or dolomitisation.*

Sample	Rock type	Textural components (%)									dolomite mean rhomb/ grain size	I.R. (%)	Comments
		micrite	spar	dm	qz	skeletal grains: total	ech	foram	bra	etc			
Tyrrellfjellet member													
349	clastic dolomite			91	9						f.micg	15	
338	clastic dolomite		1	98	1						vfg	4	bioturbated
333	clastic dolomite			100		(61)	?		?		mg	2	grains of dm + fossil ghosts
323	clastic dolomite			97	2	1				+	vfg	4	oolite ghosts in dm mud
320	clastic dolomite			99	1	(2)	?				vfg	2	
315	clastic dolomite		2	93	5	(80)	?		?		mg	6	dolomite laths
305	clastic dolomite		2	97	1	(9)	(2)			(7)	fg	3	
300	dolomite			94	6						c.micx	9	
291	dolomite		1	99		(2)				?	vfg	8	
290	dolomite		4	94	2						f.micx	9	
288	clastic dolomite		19	81		(27)	(2)	(2)			fg	8	dm grains, spar cement
285	clastic dolomite		28	68	4						mg	2	
282	dolomite (oolite)		3	93	2	..					f.micx	3	oolite ghosts
272	dolomitic biomic	43		53		4	4				fx	1	
Minkinfjellet and Cadellfjellet members													
270	dolomitic biomic	(39)	39	52		8	8				fx	1	micrite rexd before dmn.
265	partly rexd. biomic	81	7		2	10	5		2	3		3	fossils partly rexd.

(contd)

Table 1 (contd)

Sample	Rock type	Textural components (%): micrite	spar	dm	qz	skeletal grains: total	ech	foram	bra	etc	dolomite mean rhomb/grain size	I.R. (%)	Comments
Minkinfjellet and Cadellfjellet members (contd)													
262	partly rexd. biomic	(91)	96		1	4	2	2				1	fossils partly rexd.
250	biomicrite	74	12	3		9	2	7			vfx	0	spar infills forams, 2% pel
247	biomicrite	68	1	3	3	25	12	2	6	5	vfx	4	
240	biomicrite	90			2	8	8					2	
235	marble											4	high contact metamorphism
204 to 234 above sea level: dolerite sill													
200	partly rexd. biomic	84	16			(16)	?					4	fossils rexd.
197	partly rexd. biomic	58	42			(42)	?		?			2	
190	biomicrite	76	5		1	19	5	5	4	5		3	
185B	dolomitic biomic	51	4	11		33	13	9	5	6	c.mic/vfx	5	
185A	dolomitic limest		59	40		1	+			+		3	rexd. to spar before dmn
180	biomicrite	78	3	1		18	3	1	7	7		2	
175A	dolomitic limest		53	47							c.micx	3	fossil ghosts in spar
175	biopelsparite		38			26		24	+	1		2	36% pel
170	dolomitic biomic	45		48	1	7	3	+	+	3	mic/fx	4	
165	dismicrite	78	15		7		?		?			7	spar is result of dedmn
154	dolomite		2	97	1						fx	3	zonar dm rhombs
152	dolomite										f/mx	1	
150	dolomite			99	1						vfx	13	
143	biomicrite	78	3		1	19	5	+	3	11		2	8% bivalve débris
142	dolomite										c.micx	2	zonar dm rhombs
141	dolomitic limest		48	52			?	?			fx	9	fossil ghosts in spar

Table 2

Microfacies analyses of samples from the Gipshuken Formation on Mjølnerfjellet. Secondary quartz denoted by "s"; key otherwise as in Table 1.

Sample	Rock type	Textural components (%)									dolomite mean rhomb/ grain size	I.R. (%)	Comments
						skeletal grains							
		micrite	spar	dm	qz	total	ech	foram	bra	etc			
510	chert											100	sponge spicules
494	silicified sandy 1st											98	sponge spicules
456	dolomite		10	89	1	(5)					crypx	5	fossils rexd to spar
432	dolomite		2	91	s. 7						cryp/micx	8	2dary idiomorphic qz
421	partly rexd biomic		29	71		(29)					cryp/micx	1	fossils rexd to spar
420	dolomite		7	93		(7)	?	?	?		cryp/micx	3	fossils rexd to spar
412	dolomite		22	78							cryp/micx	1	
409	dolomite		35	65							cryp/micx	2	
404	dolomite		4	96	+						cryp/micx	1	
398	partly rexd biomic	66	20		s. 7	7	3		2	2		4	idiomorphic qz, relict ct
396	dolomite		11	89							cryp/micx	2	
390	dolomitic micrite	38	10	52		(10)	?		?		crypx	1	
385	micrite	100										3	
370	breccia of dedmd. clastic dolomite					..						6	

mites of the Tyrrellfjellet Member and those seen in the Minkinfjellet Member. These uppermost dolomites are much more finely crystalline and consist of dolomite mud with interspersed microcrystalline rhombs. The terrigenous content here is lower than that seen in the underlying Nordenskiöldbreen Formation (mean 2.1%).

The top of the Gipshuken Formation cannot be identified with certainty on Mjølnerfjellet, although the silicified scree seen uppermost may belong to the overlying Kapp Starostin Formation.

KAPP STAROSTIN FORMATION

A section through this formation was examined on Eremitten, approximately 45 km SE of Mjølnerfjellet (Fig. 3 and Table 3). Exposure is poor, and the probable base of the formation is covered by scree. Silicification is extensive throughout this unit, and this is accompanied by recrystallization of much of the original limestone. However the succession is dominated by originally sandy biosparites; the bioclastic fraction is dominated by brachiopod débris, in marked contrast to the lower formations seen in Lomfjorden. Glauconite is seen in most specimens, although never in large quantities. These properties suggest a correlation with the Hovtinden Member of this formation. Minor shaly horizons and dolomites also occur, while biomicrites occur only in the beds immediately below the junction with overlying Triassic shales.

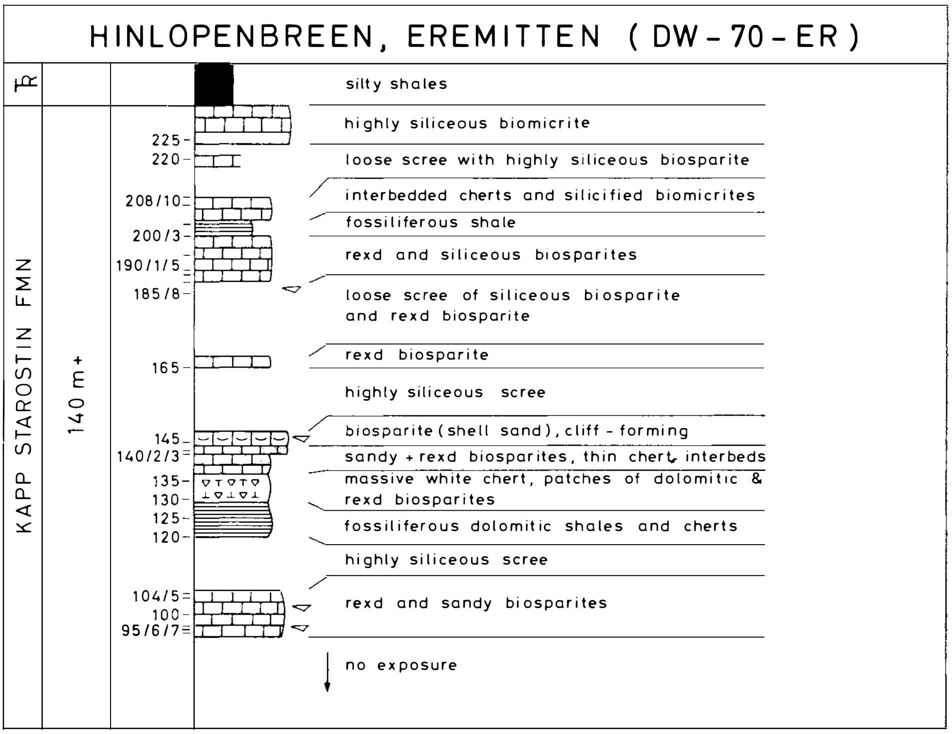


Fig. 3. *Eremitten section; key as in Fig. 2. Although the whole section is extensively silicified, the only chert indicated here is a prominent bed at 130 metres above sea-level.*

Table 3

Microfacies analyses of samples from the Kapp Starostin Formation on Eremitten. Abbreviations: glauc (glauconite), spic (sponge spicules). Otherwise, key as in Table 1.

Sample	Rock type	Textural components (%) micrite	spar	dm	qz	chert	glauc	skeletal grains total	ech	bra	spic	etc	I.R. (%)	Comments
225	cherty biomic	9			4	59	3	26			+		54	
220	biosparite		47			1		53	7	42		3	7	shell sand bank
210	rexd biomic	(24)	7		1		1	(72)					2	
208	cherty biomic	9	2			41	5	42	2	24		16	43	bivalves and bryozoans common
203	fossiliferous shale				1		1	50					49	IR mostly clay, ostracodes common
200	rexd sandy biosp.		78		10	1	1	(12+)		(7)		(4)	7	fine sand
195	rexd biosparite		95		4		+	(?)					7	fossil ghosts
191	rexd biosparite		94		5		1	(?)					6	fossil ghosts
190	cherty biosparite		18		6	71	3	(?)			+		80	sponge spicules in chert
188	rexd biosparite		93		6		1	(?)					4	fossil ghosts
185	biosparite		52		1		+	47	+	26	5	15	26	algae encrust shell débris
165	rexd biosparite		97		3		+	(?)					2	brachiopod ghosts
145	biosparite		16		2		+	81		80		1	3	shell sand bank
143	calcareous sst		37	+	53	+	4	6		4		1	61	sub-round medg sand
142,5	sandy biosparite		21		41	6	+	32		29		3	42	sub-round medg sand
140	rexd biosparite		93	2	4		1	(?)						fossil ghosts
135B	rexd biosparite		92		8		1	(10)						fossil ghosts
135A	chert					84	+	15			15		89	calcareous sponge spicules
130	dolomitic rexd biosp.		69	26	2		+	(?)		?			5	brachiopod ghosts
125	fossiliferous dm shale			14	3			15		+			74	IR mostly clay
120	fossiliferous dm shale		32	12			1	(32)				?	56	IR mostly clay
105	chert		3	1		95	1				+		96	
104	rexd sandy biosp.		84		14		1	(10+)						fine sand, fossil ghosts
100	rexd sandy biosp.		78		21		1	(7+)					22	fine sand, fossil ghosts
97	sandy biosparite		38		34		+	28	+	++	+			med. sand, some clastic ct
96	biosparite		46	+	2	14		37	8	24		5	32	some clastic ct
95	sandy biosparite		54		9		1	35	+	+	+		11	med. sand, some clastic ct

Summary

The Svenbreen Formation is apparently thicker in this area than previously assumed; its distribution on the eastern coast of Lomfjorden is more restricted than indicated by CUTBILL (1968). The Nordenskiöldbreen and Gipshuken Formations are somewhat thinner in Lomfjorden than further south in Ny Friesland. Dolomite is much more common than might be expected from studies to the south, while the clastic content of these formations is unexpectedly low. Sedimentation in relatively low energy lagoonal or extremely shallow water conditions is suggested, and the Tyrrellfjellet Member is characterised by the erosion and redeposition of early diagenetic dolomite.

The Kapp Starostin Formation consists mainly of sandy biosparites with glauconite. These beds were probably deposited as sandy shellbanks in high energy environments. This formation is also characterised by extensive silicification of the original sandy limestones.

References

CUTBILL, J. L., 1968: Carboniferous and Permian stratigraphy of Ny Friesland, Spitsbergen. *Norsk Polarinst. Årbok* 1962, 12–24.

CUTBILL, J. L. and A. CHALLINOR, 1965: Revision of the stratigraphical scheme for the Carboniferous and Permian rocks of Spitsbergen and Bjørnøya. *Geol. Mag.* **102,** 418–439.

GOBBETT, D. J., 1964: Carboniferous and Permian brachiopods ot Svalbard. *Norsk Polarinst. Skr.*, No. 127.

KULLING, O., 1934: The Hecla Hoek Formation round Hinlopenstredet. *Geog. Annaler,* **16,** 161–254.

LEIGHTON, M. W. and C. PENDEXTER, 1961: Carbonate rock types, 33–61 in "Classification of Carbonate rocks", ed. W. E. HAM, *Amer. Ass. Petrol. Geol.*, Mem. 1.

LOWELL, J. D., 1968: Upper Palaeozoic and Lower Mesozoic stratigraphy of south-western Nordaustlandet, Spitsbergen. *Geol. Mag.* **105**, 348–355.

ORVIN, A. K., 1940: Outline of the Geological History of Spitsbergen. *Skr. Svalbard og Ishavet.* No. 78.

WINSNES, T. S., 1966: Observations on the Carboniferous and Permian rocks of Vestspitsbergen. *Norsk Polarinst. Årbok* 1964, 7–29.

The petrology of some Carboniferous and Permian rocks from Bjørnøya, Svalbard

By Anna Siedlecka[1]

Contents

Abstract

Thin sections of terrigenous and carbonate rocks from the Upper Palaeozoic Fusulina Limestone and Spirifer Limestone formations of the northern part of Bjørnøya (19°E, 74°30′N) have been examined. Recognition of sedimentary environments and diagenesis constitutes the main objective of this study.

A section measured through the upper part of the Fusulina Limestone Formation consists dominantly of dolomitized biomicrites and finely crystalline dolomites and is representative of a sabkha and subordinate lagoonal environment. Two basal sections from the Spirifer Limestone Formation are composed chiefly of quartzarenites in their upper and lower parts while biosparites are dominant in the middle of the sections. The quartzarenites are representative of desert deposits reworked in a beach environment while the biosparites are interpreted as calcareous sand banks originating in the marginal zone of the shelf.

Authigenic minerals recorded in rocks of both formations are indicative of fluctuating either hypersaline or normal to fresh-water conditions thus constituting a set diagnostic of a schizohaline environment as defined by Folk & Siedlecka (1974).

[1] Norges Geologiske Undersøkelse, P.O. Box 3006, 7001 Trondheim.

Introduction

During the summer of 1964, as a leader of one of the field parties sent out by Norsk Polarinstitutt, Dr. S. SIEDLECKI carried out geological investigations on Svalbard. By this opportunity some stratigraphic sections of the Carboniferous and Permian on Bjørnøya were measured and collections of fossils and rock specimens were sampled from these sections.

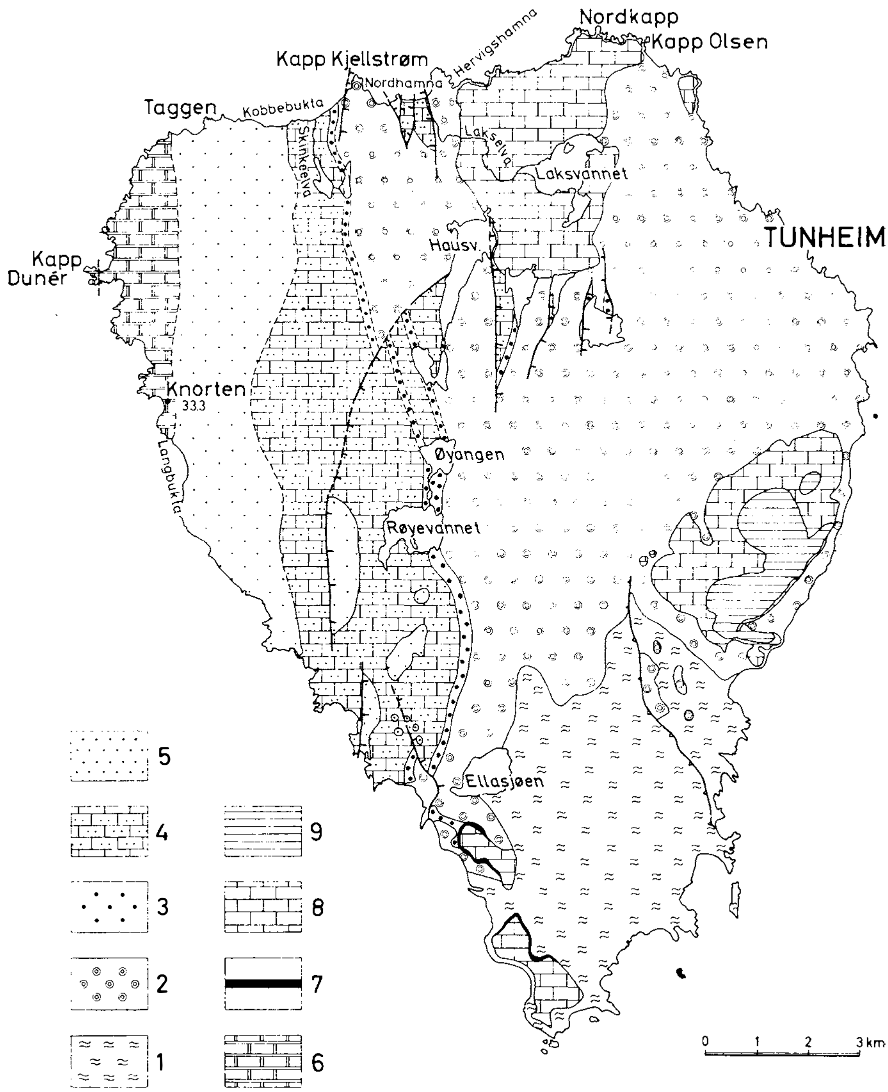


Fig. 1. *Geological map of Bjørnøya* (*after* HORN & ORVIN *1928, simplified*).

1 – Lower Paleozoic
2 – Lower Carboniferous
3 – 8 Upper Carboniferous and Permian
3 – Red Conglomerate
4 – Ambiqua Limestone
5 – Yellow Sandstone
6 – Fusulina Limestone
7 – Cora Limestone
8 – Spirifer Limestone
9 – Triassic

This note deals with rocks of the Fusulina Limestone and Spirifer Limestone formations and is based on examination of thin sections from three geological sections measured by S. SIEDLECKI (unpublished data) in the northern part of the island, at Kapp Dunér, in Hervigshamna, and at Kapp Olsen (Fig. 1); results of the measurements are shown, with permission, on Figs. 2, 3, and 4.

Middle Carboniferous, Upper Carboniferous and Permian deposits of Bjørnøya (19°E, 74°30'N) are represented by terrigenous and carbonate rocks which on the basis of lithology, typical fauna and disconformities, have been divided into the following six stratigraphic units (ANDERSSON 1900; HOLTEDAHL 1920; HORN and ORVIN 1928):

6. Spirifer Limestone	(120 m)	
	—————disconformity	
5. Cora Limestone	(50 m)	
	—————disconformity	
4. Fusulina Limestone	(75 m)	
3. Yellow Sandstone	(150 m)	
2. Ambigua Limestone	(175 m)	
1. Red Conglomerate	(145 m)	

(maximum thicknesses are cited; they decrease towards the North)

The precise age of these units is, as yet, not definitely established. At first they were considered as Middle- and Upper-Carboniferous (ANDERSSON 1900; HOLTEDAHL 1920; HORN and ORVIN 1928). Later ORVIN (1940) regarded these sediments as younger, formed in the upper part of Middle Carboniferous, Upper Carboniferous and Permian. Recently CUTBILL and CHALLINOR (1965) even suggested an Upper Permian age for the Spirifer Limestone, and discussion on this topic does not seem to be finished.

The above lithostratigraphic units consist mostly of marine sediments; units 1–4 form a continuous succession resting unconformably on Lower Carboniferous (?Namurian) deposits. These units are tilted toward the west and are preserved only in the western part of the island (Fig. 1). The Cora Limestone rests unconformably on the Red Conglomerate or on Lower Carboniferous or even directly on Lower Palaeozoic rocks and, due to restricted deposition and/or erosion, occurs only in the southernmost part of Bjørnøya. The Spirifer Limestone rests on Lower Carboniferous in the northern and eastern parts of the island (locally on the Yellow Sandstone); small patches of this formation present in the southern part of Bjørnøya rest on the Cora Limestone or directly on Lower Palaeozoic rocks.

As with Spitsbergen, Bjørnøya is situated close to the western edge of the Barents Sea Shelf Platform (FREBOLD 1951) which has existed since the Palaeozoic and the above outlined pattern of distribution of lithostratigraphic units reflects periods of (1) deposition, (2) nondepostion and/or erosion, and (3) tectonic (epeirogenic) movements which were active in this region.

Little attention has been paid to petrology of the rocks constituting the above-mentioned units, and the general lithologic characteristics given by ANDERSSON (1900), HOLTEDAHL (1920), and by HORN and ORVIN (1928) are until today the most detailed published information on the Permo-Carboniferous rocks of Bjørnøya.

The aim of the present study was to determine petrological properties of rock types and to interprete their sedimentary environment and diagenesis. The conclusions reached are necessarily incomplete because the field observations were not carried out with special attention paid to sedimentological or petrological properties of rock types and because the samples were relatively few and unevenly distributed.

Description of rocks

The sections through the Fusulina Limestone and the Spirifer Limestone formations consist chiefly of carbonate rocks with a subordinate admixture of terrigenous material, and of terrigenous rocks. Petrographic classification and terminology introduced by FOLK (1959, 1962, 1968) was adopted in descriptions of both the carbonate and the terrigenous rocks. For convenience of description all constituents of the studied rocks have been divided into three main groups: (1) terrigenous, (2) allochemical, and (3) authigenic. Rock names have been shown on the lithologic columns of the measured sections on Figs. 2, 3, and 4.

FUSULINA LIMESTONE

Petrography

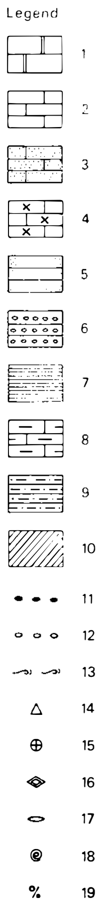
At Kapp Dunér where a section through the upper part of the Fusulina Limestone has been measured, this formation consists chiefly of finely crystalline dolomites, dolomitized biomicrites, dolomitized biodismicrites and dolomitized fusulinid biomicrites (Fig. 2). Most of these rocks contain an admixture of terrigenous material. The constituents are mostly randomly oriented and distributed; in a few cases uneven lamination can be seen or direction of layering is emphasized, e.g. by flat-lying fragments of shells or fusulinid tests.

1. *Terrigenous constituents.*

Silt-sized subangular quartz is dominant; sand-sized quartz (up to 0.5 mm, sporadically up to 1 mm) appears in the middle of the section. The sand-sized material is usually subangular; however, some rounded grains and some subrounded broken particles have been recorded. This is mostly common quartz often with numerous minute mineral inclusions; rutile needles and zircon were recognized. Overgrowths on grains of common quartz occur fairly often. Some grains of vein quartz, of recrystallined metamorphic quartz and of stretched metamorphic quartz have been recorded, the latter usually including minute muscovite flakes. Several sand-sized grains of finely crystalline chert and one

Legend and abbreviations on Figs. 2, 3, and 4:

1 – dolomite
2 – limestone
3 – arenaceous limestone
4 – cherty limestone
5 – sandstone
6 – conglomerate
7 – shale
8 – calcareous mudstone
9 – mudstone
10 – Lower Carboniferous
11 – chert nodules
12 – calcite concretions
13 – deformational sedimentary structures
14 – sulphates: mineral and/or textural relicts
15 – length-slow chalcedony
16 – zoned, water-clear dolomite rhombs
17 – fusulinids
18 – other fossils (undifferentiated
19 – bimodality
vfxn – very finely-crystalline
fxn – finely-crystalline
mxn – medium-crystalline
vcgn – very coarse-grained
cgn – coarse-grained
mdgn – medium-grained
fngn – fine-grained
vfgn – very fine-grained.



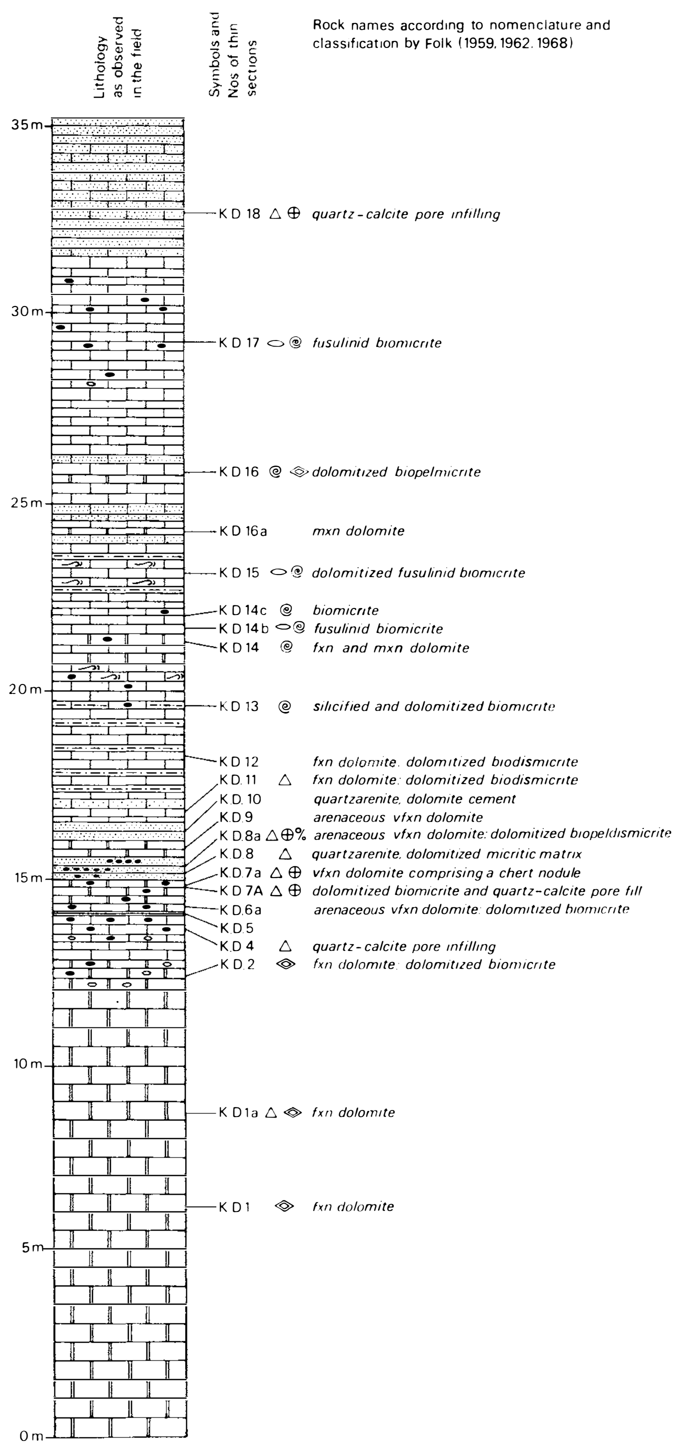


Fig. 2. *Profile of Fusulina Limestone at Kapp Dunér.*

grain of spiculitic chert were seen in the middle part of the section. The finely crystalline cherts usually include pyrite cubes up to 10μ across. Muscovite, feldspar, tourmaline and zircone are the accessory terrigenous constituents.

In general, some igneous and/or sedimentary rocks constituted the source area of this terrigenous material while metamorphic rocks were far more subordinate. Differences in roundness of sand-sized quartz indicate derivation of this mineral from different sources (?different sedimentary rocks or ?igneous vs. sedimentary source area).

On Bjørnøya and other islands of the Svalbard archipelago there is no evidence of igneous rocks which could have contributed as a source area of the Fusulina Limestone deposits. On the other hand, Devonian and Carboniferous terrigenous strata are widespread in this region and these may well be thought to be the main source of supply, whilst the metamorphic Caledonian complex of the Hecla Hoek Group could have constituted a subordinate source.

2. *Allochemical constituents.*

Allochems are present in almost all thin sections, although more or less obliterated by dolomitization. Fossils constitute the dominant type of allochems; either entire fossils such as forams, or broken fragments such as brachiopods are present.

Entire tests of fusulinids, up to 7 mm long, are fairly common especially in the middle and upper parts of the profile. In non- or slightly dolomitized rocks the tests of fusulinids consist of micrite, while internal chambers are filled with sparry calcite (Pl. I, 1). In dolomitized limestones the outlines of the fusulinid tests become hazy, their walls being composed of micrite and finely-crystalline dolomite analogous to the host rock. The internal chambers are filled partly with sparry calcite, partly with dolomite rhombs. Some of them exhibit an authigenic quartz infilling in central parts of the chambers. The fusulinids are neither broken nor worn, are often flat lying 'floating' in a micritic or biomicritic matrix, and are probably preserved in situ or only slightly transported.

A second type of fossil appearing relatively often is siliceous sponge spicules (Pl. I, 4). They are smooth monaxons ca. 0.05–0.09 mm in diameter and consist of chalcedonic silica. Axial canals of the spicules are filled either with chalcedonic silica or, less commonly, with finely crystalline dolomite. One partly dolomitized spicule (in slide K.D.4) was recorded. The siliceous sponge spicules are common in the part of the profile which contains numerous chert nodules (see Fig. 2) and have probably been the source of silica.

Gastropods, small forams, crinoid stems, spines of echinoderms, fragments of calcareous brachiopod shells and spines, ?ostracods and ?calcisphaeres appear in differing amounts within the micritic matrix along with some non-recognizable "fossil hash" or "fossil ghosts", the latter in dolomitized varieties of limestones. Ghosts of pellets have also been recorded in dolomitized limestone (Pl. I, 2; Pl. III, 2).

3. *Authigenic constituents.*

(1) *Authigenic silica.* — Three varieties of authigenic silica have been recognized: (a) megaquartz, (b) chalcedonic silica (length-slow and length-fast varieties), and (c) microcrystalline quartz (Pl. I, 3; Pl. II, 2–5). All these varieties of silica include relicts of fibrous texture and mineral inclusions of sulphates and represent a product of replacement (Pl. II, 2–6). The length-slow variety of chalcedony exhibits a close relation to sulphates: it forms complete pseudomorphs after gypsum nodules (Pl. II, 2, 3, 5, 6) and this particular association has been described elsewhere (SIEDLECKA 1972). As reported by PITTMAN and FOLK (1970, 1971) and FOLK and PITTMAN (1971), length-slow chalcedony is diagnostic in recognizing the evaporitic environment even if the evaporites are not preserved; the association length-slow chalcedony/relicts of sulphates as ubiquitously observed in the rocks of Fusulina Limestone, constitutes an excellent confirmation of the statement of the above-mentioned authors.

Chalcedony also replaces calcareous shells and forms sponge spicules. The spicule-forming chalcedony (length-fast variety) probably resulted by inversion from opal or cristobalite; no relicts of opal have been recorded and this process may only be inferred based on the generally known fact that siliceous sponges form opaline (or made of cristobalite) spicules and on the generally accepted opinion that opaline silica is unstable and converts into stable quartz varieties.

(2) *Sulphates.* — One few milimetres large pore, filled up with either barite or celestite in hypidiomorphic crystals 1 mm across has been recorded. Besides, (see description of the authigenic silica) relict fibrous texture of gypsum is common in authigenic silica and minute inclusions of sulphates (gypsum and/or anhydrite) paralleling the relict fibrous texture have been recorded both in the authigenic silica (Pl. II, 4, 6) and in sparry calcite. The latter occasionally forms pseudomorphs after idiomorphic sulphate crystals.

(3) *Calcite* — (a) Micrite constitutes the dominant variety of calcite and the main constituent of all non-dolomitized limestones.

(b) Sparry calcite, equant, medium to very coarse, constitutes infilling of pores and joints and replaces some fossils. Only one generation of sparry calcite cement has been recognized; its very coarse poikilitic variety constitutes an especially common and characteristic pore infilling in dolomites. The sparry calcite is believed by the author to be representative of fresh-water meteoric cementation, this idea being based on data and conclusions put forward by several investigators of carbonate cements (FRIEDMAN 1964, 1968; LAND et al. 1967; FOLK 1971).

(4) *Dolomite.* — (a) Very finely crystalline dolomite forming hypidiomorphic crystals $<10\mu$ across (Pl. III, 4). Traces of crinkled lamination, ghosts of pellets and fossils are preserved within this very finely crystalline dolomite (Pl. I, 2; Pl. III, 2) which is thought to be representative of a penecontemporaneous hypersaline dolomite forming in supratidal environments as e.g. in the Florida

Bay (SHINN 1964; ATWOOD and BUBB 1968), Bahamas (SHINN et al. 1965), and in the Persian Gulf (ILLING et al. 1965).

(b) Perfect, sharply outlined rhombs of water clear dolomite ca. 50μ–100μ across, occur in pores of the dolomitic rocks consisting essentially of the above-described (a) variety of dolomite (Pl. III, 2, 3, 6). The rhombs of this limpid dolomite (term introduced by R. L. FOLK, personal comm.) are usually associated with coarse poikilitic sparry calcite sealing pores. Some of these rhombs exhibit a very fine zonation in their outer parts, others are composed of two distinctly separated zones: 1) the inner zone, round-shaped or rhombic with obtuse edges and 2) the outer zone, consisting of one or several subzones. Both the inner and outer zone of these particular crystals of dolomite exhibit the same optical orientation, the refractive indexes being different. Moreover, the inner zone of a zoned crystal may contain calcite inclusions while the outer part of crystal is essentially clear. Still other rhombs of dolomite exhibit a round-shaped hole in their inner parts (Pl. III, 5).

Perfect crystals of limpid dolomite have been observed in Cretaceous limestones of the Glen Rose and Edwards formations of Texas and in Eocene limestones on Cayman island in a mineral association and general geologic setting suggesting strongly its fresh water provenance (R. L. FOLK, personal comm.). Origin of dolomite under normal salinity or fresh water conditions has been reported by LAND and EPSTEIN (1970) from Pleistocene of Jamaica. MÜLLER (1970) and MÜLLER et al. (1972) reported authigenic dolomite from lacustrine environments where not salinity but Mg^{2+}/Ca^{2+} ratio (ca. 7–15) and presence of high-Mg calcite are decisive in formation of this mineral. Rhombs of the water-clear, often zoned dolomite rhombs observed in Fusulina Limestone, are invariably associated with blocky coarse (low-Mg) calcite. This association suggests that there is a genetic interrelation between these two minerals, namely a fresh-water origin. It is believed that changes of Mg^{2+}/Ca^{2+} ratio have been a decisive factor controlling formation of either of these two minerals. Dolomite may either represent a product of replacement of sparry calcite, as inclusions of calcite appear in some of the limpid dolomite crystals, or of direct precipitation, or both. On the other hand, some of the calcite could have resulted by dedolomitization.

(c) A mosaic of hypidiomorphic crystals 30μ–100μ across, usually dirty, full of minute inclusions (Pl. III, 1). This variety of dolomite represents a volumetrically important neomorphic product and may originate by replacement of very finely crystalline hypersaline dolomite, especially when sizes of crystals being diagnostic of both varieties of dolomite are present in one rock. This variety of dolomite also constitutes neomorphic cement of quartzarenites. The partial dolomitization by replacement affected also some fusulinid biomicrites although, owing to sizes of dolomite crystals and to preservation of fill of chambers of fusulinid tests (sparry poikilitic calcite and limpid dolomite), it is equally possible that penecontemporaneous hypersaline dolomitization occurred, predating later replacement. It is often hard to say which of these processes occurred or which was more extensive; it is however evident that both have been taking place, attacking different parts of the primary deposit with different intensity.

(5) *Pyrite.* — Cubes of pyrite occur usually within carbonate and silica infillings of cavities, and sometimes are scattered throughout the rocks.

(6) *Iron oxides* are scattered throughout the rocks, especially the dolomitic specimens, and most commonly appear in carbonate-filled joints, representing products of weathering of both pyrite and of occasionally-recorded ferroan dolomite.

Sedimentary environment and diagenesis of the Fusulina Limestone

The finely- to medium-crystalline replacement dolomite and the finely-crystalline variety of dolomite with relicts of primary textures, representative of hypersaline supratidal conditions, occur in the lower part of the Kapp Dunér section (Fig. 2). Higher up in this section, the partly dolomitized biomicrites constitute the predominant lithology, being representative of a lime mud which has accumulated in an environment protected from strong current and wave activity. The biomicrites comprise fine "fossil hash", fusulinids (restricted to some horizons) and occasionally macrofossils: the brachiopods *Camerophoria isoryncha* M'Coy, and *Syringopora ramulosa* Goldfuss have been identified by Andersson (1900). Besides, within the middle and upper parts of the section there occur numerous chert nodules consisting largely of length-slow chalcedony and exhibiting relict fibrous texture of sulphates (Siedlecka 1972). It seems that the fusulinid horizons are usually free of cherts and sulphate relicts and vice versa, this, however, not being a very distinct relationship (see Fig. 2).

The presence of evaporites and of length-slow chalcedony typical of evaporitic environments (Pittman and Folk 1970, 1971; Folk and Pittman 1971) indicates a dry hot climate and a partial subaerial exposure of the environment of deposition, and supports the above suggestion of a primary supratidal, hypersaline environment of origin for the very finely-crystalline dolomite of the lower part of the section. Bimodality of the terrigenous material in slide K.D.8a (Fig. 2, Pl. II, 5) being typical of desert reg environment (Folk 1968a) along with the calcite pseudomorph after a sulphate crystal and the hypersaline penecontemporaneous very finely-crystalline dolomite, all present in this same slide, indicate a close relation between the desert and sabkha environments.

More detailed suggestions on sedimentary environments may be made by comparison with some recent and ancient examples. The best recent examples of carbonate evaporitic environments constitute the Persian Gulf as well as some localities off Western Australia although the author feels that the analogies with the Persian Gulf sabkhas are closer. Tidal flats of sabkha type as for example those of the west coast of the Quatar Peninsula (Illing et al. 1965) or on the south side of the Khor al Bazam lagoon (Kendall and Skipwith 1969, 1969a) seem to be good comparative models.

The above-mentioned relationship between fusulinid horizons and the evaporitic horizons may be thought to reflect fluctuations of hypersaline tidal flat and lagoonal environments; in quiet bottom environment of the latter the fusulinids could probably find more favorable living conditions. In Fig. 2 it is seen that above the lower dolomitic portion of the section there appear arenaceous biomicrites with distinct traces of evaporitic environments and subordinate beds of quartzarenite. Quartz sand and silt may be interpreted as an aeolian material blown seawards and deposited both on the sabkhas and in the lagoon and partly also as a desert reg relict deposit. Its amount is larger on the tidal flats because of a slower rate of depostion of carbonate material as compared with the lagoon. Above this portion of the section (i.e. above ca. 20 m from the bottom) until ca. 30 m from the bottom, the fusulinid horizons appear and no evidence of evaporitic environment has been recorded in this particular part of the section. Then, in the upper part evidence of the evaporitic environments reappears and, simultaneously, the admixture of aeolian quartz increases. Evidence of this relationship in the upper part of the section is uncertain however since above ca. 26 m there were only two thin sections available and since chert nodules are present around 30 m (Fig. 2).

Occurrences of 1) sulphates, appearing mainly as nodules (replaced later by silica), 2) very finely crystalline dolomite, 3) sparry calcite free of inclusions, filling out irregular pores which could have originated only in a fresh sediment, and 4) associated with this spar crystals of limpid dolomite, seem all to reflect early diagenetic, penecontemporaneous to deposition processes. The sulphates and the very finely crystalline dolomite give evidence of an evaporitic hypersaline environment while the equant coarse sparry calcite is believed to be a product of fresh meteoric waters and so presumably does the limpid dolomite. Taking these data into account it becomes clear that the cementation of the sediment occurred under periods of both hypersaline or normal to fresh water conditions. These contrasting conditions could have occurred repetitively as result of evaporation and then fresh water floading or normal sea water influx. The name *schizohaline* has been suggested by FOLK and LAND (1972), SIEDLECKA (1972a), and FOLK and SIEDLECKA (1974) for this type of environment with highly variable salinity.

Concluding, a predominantly sabkha environment and schizohaline conditions are suggested for the formation of the Fusulina Limestone as observed in the Kapp Dunér section; some lagoonal deposits are present in the middle and upper parts of this section.

SPIRIFER LIMESTONE

Petrography

Basal sections of the Spirifer Limestone in the northern part of Bjørnøya at Kapp Olsen and Hervigshamna are composed of quartzarenites and fossiliferous quartzarenites in their lower and upper parts while arenaceous biosparites and biosparrudites are present in the middle of these sections (Figs. 3, 4). In

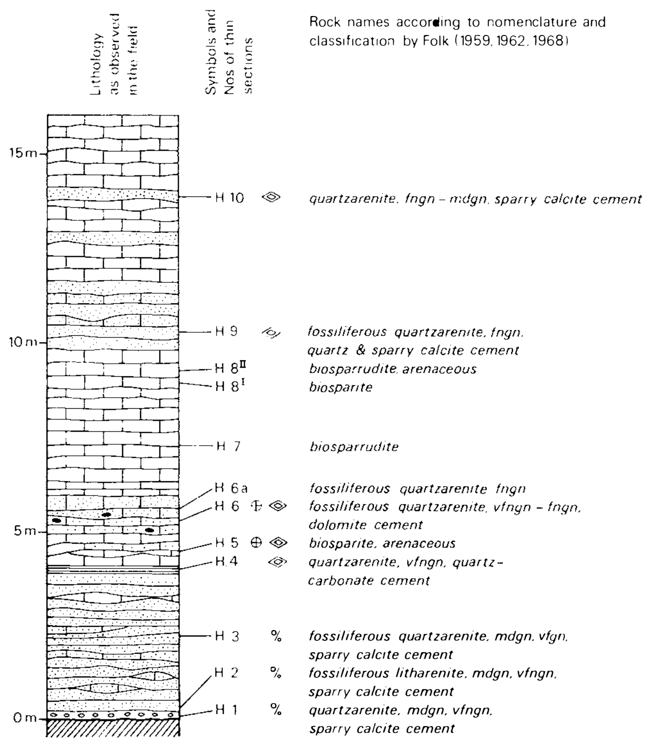


Fig. 3. *Profile of Spirifer Limestone east of Hervigshamna.*

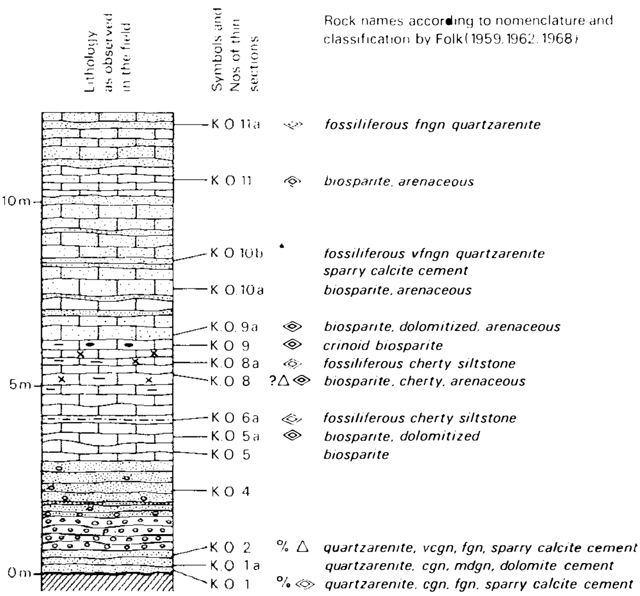


Fig. 4. *Profile of Spirifer Limestone at Kapp Olsen.*

addition, fossiliferous cherty siltstones occur in the middle, carbonate-rich part of the Kapp Olsen profile (Fig. 4).

Sorting of the terrigenous material is moderate to good; the quartzarenites of the lower parts of these sections exhibit a distinct bimodality: ca. 0.5–1 mm (interval of the coarser grains) and ca. 0.05–0.1 mm (interval of the finer grains), (Pl. IV, 1, 2) – a feature characteristic of desert reg sands (Folk 1968a). Calcarenites and calcirudites are moderately to well sorted; the subrounded flat particles of shells are randomly oriented rather than flat-lying and the structure of these particular rocks is commonly homogenous, sometimes indistinctly laminated. Such features are in general characteristic of high energy environments (beaches, back- and fore-reef banks, etc.) of recent carbonate deposition.

1. *Terrigenous constituents.*

Sand- and silt-sized grains of common quartz are dominant. The grains are either subangular or subrounded, rounded sand grains being subordinate. Overgrowths prior to deposition were recorded on some of the sand-sized grains in almost all thin sections. Grains of metamorphic recrystallized quartz and metamorphic stretched quartz are rare. Chert in amounts of a few grains in slide were recorded, especially in the lower part of the profile. These are mostly grains of microcrystalline quartz or of microcrystalline and chalcedonic quartz; however, grains of spiculitic chert, a grain containing a foram test and one grain with ghosts of radiolarians were observed. Several grains of chert are transsected by quartz veinlets giving evidence of tectonic disturbance of the source area. Chert grains appear commonly brownish in transmitted light due to presence of minute air bubbles; besides, many of them contain minute cubes and dust of pyrite. In addition to the above-enumerated chert varieties, several detrital grains of spherulitic length-slow chalcedony have been recorded in slides K.O.1a and H.2 (lower part of the formation).

In general, both an igneous and a sedimentary source area may be inferred based on the terrigenous components of the Spirifer Limestone. A metamorphic source seems to be subordinate. It is difficult to say whether reworking of the local substratum or transport from a remote area of supply took place as a predominating process. Provenance from the underlying sedimentary rocks is highly probable in this geological setting characterized by several short transgression/regression periods; on the other hand, however, one should expect a larger admixture of metamorphic material deriving from the Hecla Hoek metamorphic rocks outcropping in the southern part of Bjørnøya, if the area of supply was local.

2. *Allochemical constituents.*

Fossils constitute the only type of allochems present in the Spirifer Limestone of the northern part of Bjørnøya and three groups of organisms apparently dominate there throughout both sections: brachiopods, bryozoans and echinoderms (mainly crinoids) (Pl. IV, 3). Sponge spicules are subordinate and restricted to a few particular beds while small forams and gastropods appear rather sporadically. The fossils are broken to sand to granule-sized particles with some larger fragments and possibly entire shells scattered in between. The fragments of fossils are not much worn except for those present in the quartzarenites of the lower part of the formation. It should be pointed out that allochems in these terrigenous rocks are restricted to brachiopods while higher up in the succession all three groups of fossils are abundant, their relative amounts being variable.

Brachiopods. — These are mostly represented by productids and spiriferids. Brachiopod shells and spines consist of calcite, exhibit well preserved lamellar structure, and are generally unaltered. Some of the shells are burrowed. Central canals of spines are usually filled with one of the following minerals: 1) sparry calcite; 2) microcrystalline quartz; or 3) glauconite. The brachiopod shells are sometimes partly replaced by microcrystalline quartz and/or chalcedonic silica; fibres of the latter either follow the lamellar structure of calcite or form subparallel bundles or even spherulites. Some of the spherulites have been recognized as representative of the length-slow variety of chalcedony.

Bryozoans occur in fragments of a few millimetres up to several centimetres in size; they are mostly represented by several species of Trepostomata and Cryptostomata described recently by MALECKI (in press). The laminate and beaded structure of the calcitic walls of zoaria is usually well preserved; even if locally silicification occurred, this structure is not obliterated due to processes of replacement in solid state (Pl. IV, 3, 4). Zoecia are either empty or filled with one or several of the following minerals: 1) sparry calcite; 2) rhombs of dolomite; 3) microcrystalline quartz; 4) phosphates; or 5) glauconite.

Echinoderms. — Fragments of crinoid stems ca. 1–2 mm Ø are common while echinoid spines and fragments of plates are rare. They consist of primary sparry calcite with a distinct grid-like internal structure; some of them are partly replaced by microcrystalline and/or fibrous quartz which forms irregular patterns independent of the skeleton structure and which may be related to some non-discernible irregular fracturing. Sparry calcite often forms syntaxial overgrowth on the echinoderm fragments while internal pores of crinoid stems are often either empty or filled with dolomicrite.

Sponge spicules. — These are present in the cherty rocks of the Kapp Olsen section. The spicules are rod-shaped smooth monaxons ca. 0.025–0.1 mm in diameter. Both walls and axial canals of the spicules consist of chalcedony (Pl. II, 1) although in some cases either phosphates or glauconite constitute the axial canal fill. Some spicules consist entirely of sparry calcite, some others are in part chalcedonic and in part replaced by carbonates (dolomite, calcite).

Others. — Small gastropods and forams were recorded, their tests being of micritic calcite. Internal chambers of these fossils have been entirely filled with sparry calcite. Besides, there appear some particles of phosphatic shells, and two phosphatic pellets were recorded in the lower, arenaceous part of the formation (slide H.3).

3. *Authigenic constituents.*

(1) *Calcite.* — This is mostly medium- to coarse-crystalline equant spar forming ubiquitous cement and common joint-fill. Very thin rims of bladed sparry calcite appear occasionally around fragments of fossils in biosparites (Pl. IV, 3). The equant sparry calcite is either equidimensional within a given area of thin section (or within the entire thin section) or it may vary from ca. 30μ (lower limit of spar, FOLK 1962) to $>$1 mm across "poikilitic" cement. This last variety is of overgrowth type (FOLK 1962) while the finer varieties of the equant sparry calcite do not show any obvious relationship with a foundation. Only one generation of sparry calcite cement is discernible, this being supposed to be a product of primary precipitation in pores. Since the bladed variety is largely subordinate and since no fibrous calcite has been recorded, a fresh water origin is suggested for this equant blocky cement. Occasionally observed sparry calcite replacing sponge spicules may represent a separate generation of calcium carbonate, the origin of which is hard to establish in time. Micrite is subordinate and isolated patches of it may either constitute remnants of primary micrite or result of micritization. This latter process seems to be less probable since all calcitic allochems are essentially unaltered unless they are silicified.

(2) *Dolomite.* — Dolomite occurs as sharply outlined, water-clear rhombs ca. 0.05–0.15 mm across; some of the rhombs exhibit distinct growth zonation. The dolomite rhombs are scattered throughout the coarse sparry calcite cement (Pl. IV, 4). This limpid dolomite constitutes the only variety of this mineral present in the Spirifer Limestone, and is analogous to variety "(b)" of dolomite in Fusulina Limestone (see description p. 8). It is interpreted as precipitated penecontemporaneously with blocky calcite from fresh or brackish waters during an early stage of diagenesis. It is not clear whether it originated as pore-infilling or by replacement of the blocky sparry calcite; no inclusions of calcite have been found in the dolomite rhombs.

(3) *Silica.* — Silica occurs as microcrystalline quartz and chalcedonic quartz. Beside replacing fossils and infilling their chambers and channels, it impregnates rocks nonselectively (cherty rocks of the Kapp Olsen profile, see Fig. 4). In the lower part of the Kapp Olsen profile concentrations of authigenic length-slow chalcedony have been recorded (K.O.2 and K.O.8). Besides, spherulites of this same variety of chalcedony have occasionally been observed replacing brachiopod shells higher up in the section (SIEDLECKA 1972). The presence of length-slow chalcedony gives indirect evidence of an evaporitic environment (PITTMAN and FOLK 1970, 1971; FOLK and PITTMAN 1971), this evidence being supported by minute mineral inclusions of sulphates appearing in the authigenic length-slow chalcedony present in lower part of the formation (K.O.2 and K.O.8). Chalcedony forming the sponge spicules (length-fast variety) is probably a product of inversion of opal or cristobalite, while that

filling the axial canals of the spicules may be either a pore infilling or a product of replacement of another mineral.

(4) *Glauconite* forms grains of about 0.25 mm, either rounded and well defined (?pellets), or somewhat lobate and hazy. The glauconite could have been formed in situ or, similarly to allochems, transported for some distance over the sea floor and does not have any special importance in interpretation of sedimentary and diagenetic processes.

(5) *Phosphates* were recognized as an apparently authigenic, cement-forming mineral only in the upper part of the Kapp Olsen profile. In other parts of the formation in both investigated sections it may occasionally constitute fill of bryozoan zoecia or of axial canals of sponge spicules.

Sedimentary environment of the Spirifer Limestone

Quartzarenites occur mostly in the lower part of the sections but then also appear in their upper parts and are generally absent in the middle where carbonate rocks are dominant.

Bimodality of the quartzarenites in the lower part of the sections is a striking feature (Pl. IV, 2). Bimodal sands, as shown by Folk (1968a), typically composed of a mixture of 0.5–1.0 mm and 0.09–0.18 mm modes, originate in deserts, on aeolian deflation regs. Folk (1968a) states that the sands originated and accumulated on the deflation regs and later redeposited in other environments, may preserve their bimodality even if subjected to a shallow marine dynamic regime. It may therefore be supposed that the bimodal sands of the Spirifer Limestone, composed of a mixture of 0.5–1.0 mm with 0.05–0.1 mm grains originated on deflation regs and have then been incorporated into marine sediments of the encroaching Spirifer Limestone sea. The reworking of this desert-derived material is documented by presence of subrounded fragments of fossils, mostly brachiopods, some extensively burrowed.

Bimodality has not been observed in the quartzarenites of the upper part of the formation, however, scarcity of samples may constitute the reason for which this texture has not been recorded.

Carbonate rocks present in the middle and upper parts of the succession represent mostly moderately sorted submature sands composed of debris of brachiopods, bryozoans and echinoderms with addition of terrigenous quartz. No algal remains and no intraclasts have been recorded. The sedimentary environment of these sediments may be suggested either on the basis of comparison with recent carbonate environments or with some well established models known from the geological record. It seems to the author that the Permian carbonate deposits of West Texas and New Mexico constitute the best model which can be adopted in an environmental interpretation of the sediments of the Spirifer Limestone; they are of similar age and include similar fossil associations.

Leonardian and Lower Guadalupian carbonate deposits consisting of debris of productids, spiriferids, bryozoans, fusulines and crinoid columnals constituted the shelf edge facies of the Delaware Basin (BOYD 1962) and were interpreted by NEWELL et al. (1953) as sand banks accumulated at the basin margin as aprons around small patch reefs. Cherty beds containing analogous faunal detritus have been found for example in the fore-reef tract in the Lower Guadalupian San Andres Formation (BOYD 1962). In Upper Guadalupian time, while the Capitan barrier reef was growing, carbonate sands consisting of brachiopods, bryozoans, forams, crinoids and sponge spicules were deposited in marginal parts of the basin in the fore-reef tracts (NEWELL et al. 1953; TYRELL 1962), described later by TYRELL (1969) as basin slope and basin margin environments. Evaporites, dolomite mudstones, algal and peletal rocks were accumulated in the lagoonal environments at the same time as dark-coloured lime mudstones, shales and cherts originated in the basin.

Thus in general, if we take a shelf-to-basin cross section of Permian of West Texas and New Mexico as a comparative model, the carbonate rocks of the Spirifer Limestone from the northern part of Bjørnøya show a striking similarity to the facies of the marginal area of the Delaware Basin and are dissimilar to the basin or lagoonal deposits (with the exception of the calcarenite belt immediately behind the reef).

Summing up, the origin of the Spirifer Limestone Formation in the northern part of Bjørnøya in two broadly outlined sedimentary environments is suggested based on material from the described sections, namely a shore-zone where terrigenous aeolian sands and associated beach deposits accumulated, the former being reworked by the sea, and a basin margin environment where carbonate sands were deposited. There is obviously a spacial gap between these two environments, there is a general lack of record of any lagoonal, either terrigenous or carbonate sedimentation. This may be explained in following way:

The transgressive terrigenous sediments of the shore-zone (i.e. reworked desert deposits) were drowned as the transgression proceeded and incorporated into a shelf environment where essentially no deposition occurred and where the shore-zone sands could have been partly reworked similarly to relict sediments on the recent shelves.

On the drowned shore-zone deposits settlements of benthonic fauna appeared in patches which were successively destroyed by currents and waves, their debris being deposited as carbonate sands. There is no evidence of noticeable development of calcareous sponges and algae, both being the main framework-building organisms in the Permian reefs of West Texas and New Mexico (NEWELL et al. 1953; NEWELL 1955). Therefore it may be assumed that no prominent reefs originated and that the carbonate sand banks have been distributed in the marginal zone both on the shoreward and basinward sides of the patches of benthos settlements rather than being restricted to the outer marginal zone.

Terrigenous quartz has been consistently admixed to the carbonate rocks of the Spirifer Limestone, forming subordinate layers of silt and sand. A supply from the bordering land areas and from the drowned shore-zone sands may be equally inferred.

A recent environment of carbonate deposition situated in the Persian Gulf has been chosen for further comparison because the Spirifer Limestone Formation contains bimodal desert sands and some occurrences of length-slow chalcedony, (SIEDLECKA 1972; also p. 66 of this paper), giving evidence of an arid climate and of existence of an evaporitic environment, respectively. Thus, if adopting a recent environment of carbonate deposition in the Persian Gulf as a model, the following may be suggested based on KENDALL and SKIPWITH's (1969a) observations: the skeletal debris of the Spirifer Limestone biosparites could have been accumulated either on a coastal terrace or on an offshore bank. Similar distribution of skeletal debris (mostly robust molluscs, also corals, red algae, bryozoans) have been recorded by KENDALL and SKIPWITH (1969a) in the coastal area around the Khor al Bazam lagoon. However, this facies seems to be much more widespread on the offshore bank (as shown on Fig. 22 of this same paper by KENDALL and SKIPWITH 1969a) arguing for a bank environment of deposition of the Spirifer Limestone biosparites.

On the other hand, these biosparites include both some evidence of hypersaline environment (length-slow chalcedony, see p. 66) and of widespread fresh water cementation (equant sparry calcite cement, limpid dolomite, see p. 66). These changing fresh water and hypersaline conditions, the schizohaline environment of FOLK and SIEDLECKA (1974), should rather be expected on a coastal terrace where both occasional flushing of normal sea water, influence of fresh water and of periods of hypersaline conditions, the latter due to intensive evaporation, could have been acting.

The upper part of the Spirifer Limestone is not seen in the northern part of Bjørnøya (Fig. 1). This same unit is overlain by Carnian deposits in the eastern part of the island and a study of lithology of the formation in the last mentioned area could probably answer the question whether the stratigraphic gap between the Palaeozoic and Mesozoic is due to a period of non-deposition (suggested by ORVIN 1940) or to an uplift and removal of sediments.

General remarks

Interpretation of a depositional environment based exclusively on a thin section study may sometimes be deceptive. However, as shown on the previous pages, several primary features of sediment, its composition and fabric recognizable in slides are indeed diagnostic of sedimentary environment, especially if reliable comparative data are available.

Supratidal and lagoonal environments of the Fusulina Limestone represent as a whole a low-energy regime contrasting with that of the Spirifer Limestone where beach terrigenous sands and biosparites originated, giving evidence of prevailing high-energy environments. Cherty siltstones present in the middle part of the Kapp Olsen section (Fig. 4) are the only representatives of quiet conditions which could have occurred both in the inner and outer parts of offshore banks.

Evidences of a schizohaline environment are present in both formations, indicators of the hypersaline "extreme" of this environment being by far more abundant in the Fusulina Limestone. This may indicate a climatic change, and may also reflect the fact that the low energy dynamic regime is more suited both to the origin and preservation of evaporites.

The pattern of Late Paleozoic deposits of Bjørnøya is characterized by relatively frequent small-range changes of shore line recorded by disconformities between formations (see p. 55). This seems to be characteristic for the eastern part of the Barents Sea Shelf in general, since many different lithologies, mostly shallow marine, are also representative for the late Paleozoic of Spitsbergen. There are data indicating that these deposits continue beneath the Barents Sea; Permian cherty shales and calcareous sandstones with forams have been dredged from the sea bottom between Spitsbergen and Bjørnøya while organogenic limestones with Permian forams have been picked up from the area southwest of Bjørnøya (Dibner et al. 1970). So far, there is however no way to predict the facies distribution using the known ancient and recent comparative models.

Acknowledgements

Thanks are due to S. Siedlecki, Norges geologiske undersøkelse, Trondheim, for the rock samples and for making his unpublished material available. The author also wishes to express her thanks to R. L. Folk, The University of Texas at Austin, for his critical comments, discussions and inestimable help during the course of this study and preparation of the manuscript, and to Mr. G. Amaral for his assistance during the taking of Scanning Electron Microphotographs.

The study has been carried out during a stay at The University of Texas at Austin, sponsored by the Continental Shelf Division of Norges Teknisk-Naturvitenskapelige Forskningsråd (Royal Norwegian Council for Scientific and Industrial Research).

References

Andersson, J. G., 1900: Über die Stratigraphie und Tektonik der Bäreninsel. *Geol. Inst. Upsala, Bull.* **9**, Uppsala.

Atwood, K. D. and J. N. Bubb, 1968: Distribution of Dolomite in a Tidal Flat Environment, Sugarloaf Key, Florida. *Geol.Soc.Amer. Annual Meeting* (Abstr.), Mexico City.

Boyd, D. W., 1962: Leonardian and Lower Guadalupian Shelf-Edge Facies in El Paso Gap Quadrangle, Southeastern New Mexico. In: *West Texas Roswell and Hobbs Geological Societies Guidebook to the 1962 field trip*, 91–98.

CUTBILL, J. L. and A. CHALLINOR, 1965: Revision of the stratigraphical scheme for the Carboniferous and Permian rocks of Spitsbergen and Bjørnøya. *Geol.Mag.*, **102**, (3), 418–439.

DIBNER, V. D., V. A. BASOV, A. A. GERKE, M. F. SOLOV'YEVA, G. P. SISOPATROVA, and N. I. SHUL'GINA, 1970: The age of the Pre-Quaternary deposits of the bottom of the Barents Sea. *Oceanology*, **10**, (4), 520–529.

FOLK, R. L., 1959: Practical petrographic classification of limestones. *Amer. Ass. Petrol. Geol. Bull.* **43** (1), 1–38.

— 1962: Spectral subdivision of limestone types. In: HAM, W. E. (ed.), Classification of Carbonate rocks, *Amer.Ass.Petrol Geol. Mem. 1*, 62–85.

— 1965: Some aspects of recrystallization of ancient limestones. In: PRAY, L. C. and R. C. MURRAY (eds.), Dolomitization and Limestone Diagenesis, *Soc. Econ. Pal. Mineral. Spec. Publ.* **13**, 14–48.

— 1968: *Petrology of Sedimentary Rocks*, Hemphill's Draver M. University Station, Austin, Texas. 170 p.

— 1968 a: Bimodal Supermature Sandstones: Product ol the Desert Floor. *23rd Intern. Geol. Congress* **8**, 9–32.

— 1971: Carbonate Petrography in the post-Sorbian age. In: GINSBURG, R. N. (ed.), Evolving concepts in sedimentology, *The John Hopkins University Studies in Geology* **21**.

FOLK, R. L. and L. S. LAND, 1972: Mg/Ca vs. Salinity: A Frame of Reference for Crystallization of Calcite, Aragonite, and Dolomite (abstr.). *Geol. Soc. Am., Annual Meeting (Minneapolis) program*, p. 508.

FOLK, R. L. and J. S. PITTMAN, 1971: Length-slow chalcedony: a new testament for vanished evaporites. *Journ. Sed. Petr.* **41** (4), 1045–1058.

FOLK, R. L. and A. SIEDLECKA, 1974: The "schizohaline" environment: its sedimentary and diagenetic fabrics as exemplified by Late Paleozoic rocks of Bear Island, Svalbard. *Sedimentary Geology* **11** (1), 1–15.

FREBOLD, H., 1951: Geologie des Barentsshelfes. *Abhandl.deutsch.Akad.Wiss.Berlin 1950, No. 5. Abhandlung zur Geotektonik no. 4*, 1–151.

FRIEDMAN, G. M., 1964: Early diagenesis and lithification of carbonate sediments. *Journ.Sed. Petr.* **34**, 777–813.

— 1968: The fabric of carbonate cement and matrix and its dependence on the salinity of water. In: MÜLLER, G. and G. M. FRIEDMAN (eds.), *Recent Developments in Carbonate Sedimentology in Central Europe*, 11–20. New York Springer Verlag.

HOLTEDAHL, O., 1920: Spitsbergens og Bjørnøens geologi. *Naturen*, **44**.

HORN, G. and A. K. ORVIN, 1928: Geology of Bear Island. *Skrifter om Svalbard og Ishavet* Nr. 15.

ILLING, L. V., A. J. WELLS, and J. C. M. TAYLOR, 1965: Penecontemporary dolomite in the Persian Gulf. In: PRAY, L. C. and R. C. MURRAY (eds.), Dolomitization and Limestone Diagenesis, *Soc. Econ. Pal. Mineral. Spec. Publ.* **13**, 89–111.

KENDALL, C. G. St. C. and Sir P. A. d'E. SKIPWITH, 1969: Holocene shallow water carbonate and evaporite sediments of the Khor al Bazam, Abu Dhabi, southwest Persian Gulf. *Amer. Ass. Petrol. Geol. Bull.* **53**, 841–870.

— 1969a: Geomorphology of a Recent Shallow-Water Carbonate Province: Khor Al Bazam, Trucial Coast, Southwest Persian Gulf. *Geol.Soc.Am.Bull.*, **80**, 865–895.

LAND, L. S., F. T. MCKENZIE, and S. J. GOULD, 1967: Pleistocene history of Bermuda. *Geol.Soc. Am.Bull.*, **78**, 993–1006.

LAND, L. S. and S. EPSTEIN, 1970: Late Pleistocene Diagenesis and Dolomitization, North Jamaica. *Sedimentology*, **14**, 187–200.

MALECKI, J., in press: Permian Bryozoans from southern Spitsbergen and Bjørnøya.

MÜLLER, G., 1970: High-magnesian Calcite and Protodolomite in Lake Balaton (Hungary) Sediments. *Nature* **226**, 749–750.

MÜLLER, G., G. IRION, and U. FÖRSTNER, 1972: Formation and Diagenesis of Inorganic Ca-Mg Carbonates in the Lacustrine Environment. *Die Naturwissenschaften*, **59**, (4), 158–164.

NEWELL, N. D., J. K. RIGBY, A. G. FISCHER, A. J. WHITEMAN, J. E. HICKOX, and J. S. BRADLEY, 1953: *The Permian Reef Complex of the Guadalupe Mountain Region, Texas and New Mexico.* Freeman & Co. San Francisco, 236 p.

NEWELL, N. D., 1955: Depositional fabric in Permian reef limestones. *Journ.Geol.*, **63**, (4), 301–309.

ORVIN, A. K., 1940: Outline of the geological history of Spitsbergen. *Skrifter om Svalbard og Ishavet* **78**, 1–152.

PITTMAN, J. S. Jr. and R. L. FOLK, 1970: Length-slow chalcedony: a new testament for vanished evaporite minerals (abstr.), *Geol.Soc.Am., Annual Meeting (Milwaukee) program*, p. 654.

— 1971: Length-slow Chalcedony after Sulphate Evaporite Minerals in Sedimentary Rocks. *Nature Physical Science*, **230**, (11), 64–65.

SHINN, E. A., 1964: Recent dolomite, Sugarloaf Key. In: *Guidebook for Geol.Soc.Am. Field Trip No. 1, South Florida Carbonate Sediments* (compiled by R. N. GINSBURG), 62–67.

SHINN, E. A., R. N. GINSBURG, and R. M. LLOYD, 1965: Recent supratidal dolomite from Andros Island, Bahamas. In: PRAY, L. C. and R. C. MURRAY (eds.), Dolomitization and Limestone Diagenesis, *Soc. Econ. Pal. Mineral. Spec. Publ.* **13**, 112–123.

SIEDLECKA, A., 1972: Length-slow chalcedony and relicts of sulphates — evidences of evaporitic environments in the Upper Carboniferous and Permian beds of Bjørnøya, Svalbard. *Journ.Sed.Petr.* **42**(4), 812–816.

— 1972a: Sedimentary and Diagenetic Fabrics of some Late Palaeozoic Rocks of Bjørnøya, Svalbard (abstr.), *Geol.Soc.Am., Annual Meeting (Minneapolis) program*, p. 664.

TYRELL, W. W., Jr., 1962: Petrology and Stratigraphy of Near-Reef Tansill-Lamar strata, Guadalupe Mountains, Texas and New Mexico. In: *West Texas, Roswell and Hobbs Geological Societies Guidebook to the 1962 field trip*, 59–69.

— 1969: Criteria useful in interpreting environments of unlike but time-equivalent carbonate units (Tansil-Capitan-Lamar), Capitan Reef Complex, West Texas and New Mexico. *Soc. Econ. Pal. Mineral. Spec. Publ.* **14**, 80–97.

PLATES

PLATE I

1. Fusulinid biomicrite. Chambers of fusulinids filled with equant sparry calcite. Fusulina Limestone, Kapp Dunér section, thin section K.D.14b; crossed nicols.
2. Dolomitized biopelmicrite. Note ghosts of pellets. Pores filled with equant sparry calcite and water-clear dolomite. Fusulina Limestone, Kapp Dunér section, thin section K.D.16; plane polarized light.
3. Authigenic silica in a dolomitized biopeldismicrite: spherulites of length-slow chalcedony (quartzine) and idiomorphic crystals of megaquartz. Fusulina Limestone, Kapp Dunér section, thin section K.D.8a. crossed nicols.
4. Partly dolomitized and silicified biomicrite. Fusulina Limestone, Kapp Dunér section, thin section K.D.13; plane polarized light.

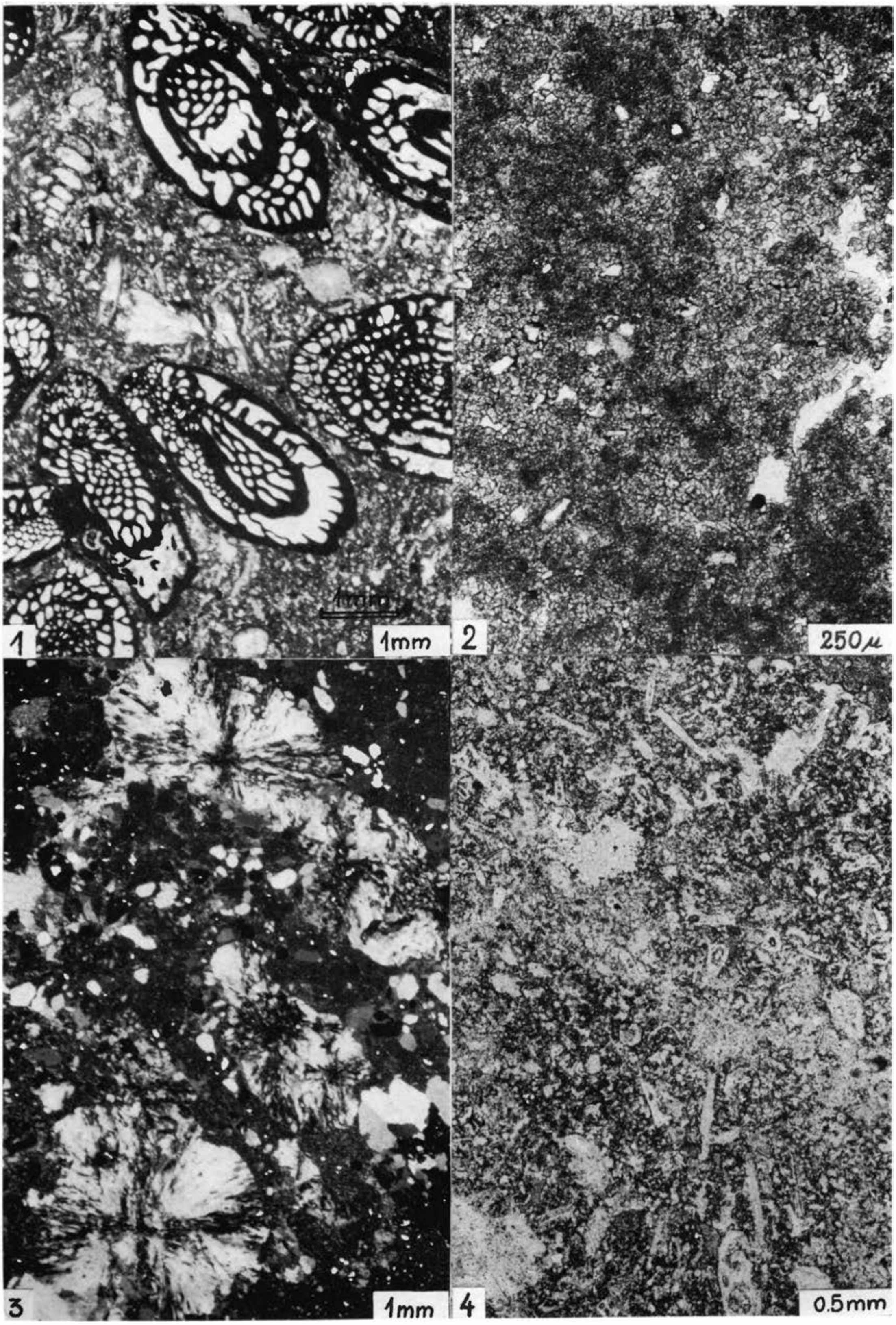

1
1mm
1mm
2
250μ
3
1mm
4
0.5mm

PLATE II

1. Fossiliferous cherty siltstone with siliceous sponge spicules (some indicated by arrows) consisting of chalcedony, axial canals being usually also filled with chalcedony. Spirifer Limestone, Kapp Olsen section, thin section K.O.8a, crossed nicols.
2. Cauliflower-shaped sulphate nodule replaced by chalcedony. Fusulina Limestone, Kapp Dunér section, sample K.D.7a.
3. Fragment of a sulphate nodule (light area) completely replaced by minute spherulites of length-slow chalcedony (quartzine). Fusulina Limestone, Kapp Dunér section, thin section K.D.7a; crossed nicols.
4. Relict mineral inclusions of sulphates preserved in idiomorphic authigenic quartz. Fusulina Limestone, Kapp Dunér section, thin section K.D.7a; plane polarized light.
5. A close-up of spherulites of quartzine shown on photo 3. Fusulina Limestone, Kapp Dunér section, thin section K.D.7a, crossed nicols.
6. Relict fibrous texture of sulphates preserved in spherulitic length-slow chalcedony. Same field and magnification as on photo 5, plane polarized light. Fusulina Limestone, Kapp Dunér section, thin section K.D.7a.

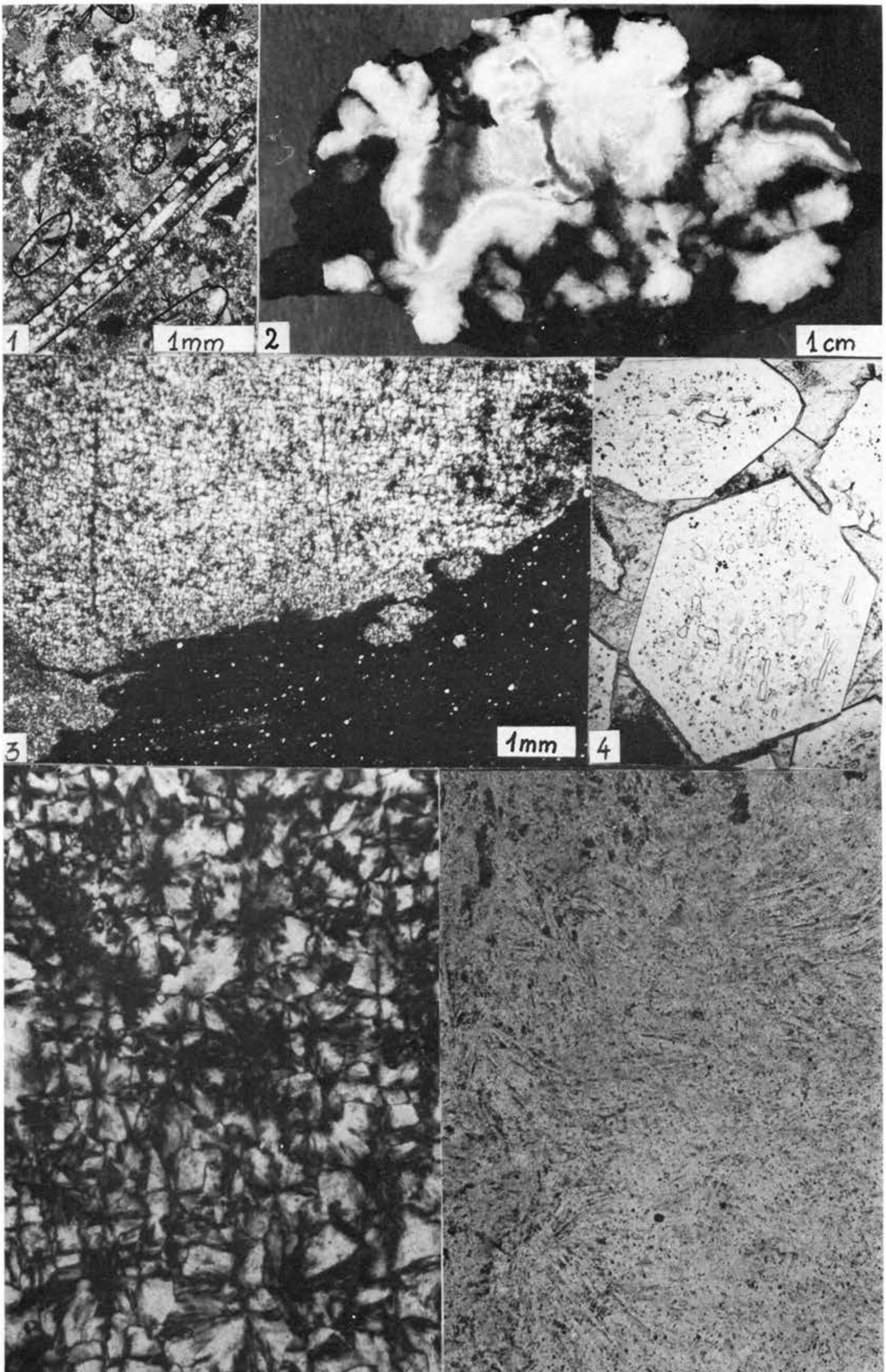

1
1mm
2
1cm
3
1mm
4
5
0.2mm
6
0.2mm

PLATE III

1. Fine- to medium crystalline replacement dolomite. Fusulina Limestone, Kapp Dunér section, thin section K.D.1; plane polarized light.
2. Relicts of pellets in a very finely-crystalline dolomite originated in a hypersaline environment. Pores are sealed with equant coarse sparry calcite and rhombs of limpid dolomite of presumed fresh-water origin. Fusulina Limestone, Kapp Dunér section, thin section K.D.2, plane polarized light.
3. Scanning Electron Microphotograph of rhombs of limpid dolomite. Fusulina Limestone, Kapp Dunér section; specimen K.D.16.
4. Scanning Electron Microphotograph of very finely-crystalline hypersaline dolomite composed of hypidiomorphic crystals contrasting in size and shape with rhombohedrons of limpid dolomite shown on photo 4. Fusulina Limestone, Kapp Dunér section; specimen K.D.6a.
5. Zoned and hollow dolomite rhombs. Fusulina Limestone, Kapp Dunér section, thin section K.D.1a, plane polarized light.
6. Scanning Electron Microphotograph of fine rhombs of dolomite originated presumably from dilute solutions. Note the hollow rhomb to the right. Fusulina Limestone, Kapp Dunér section, specimen K.D.1.

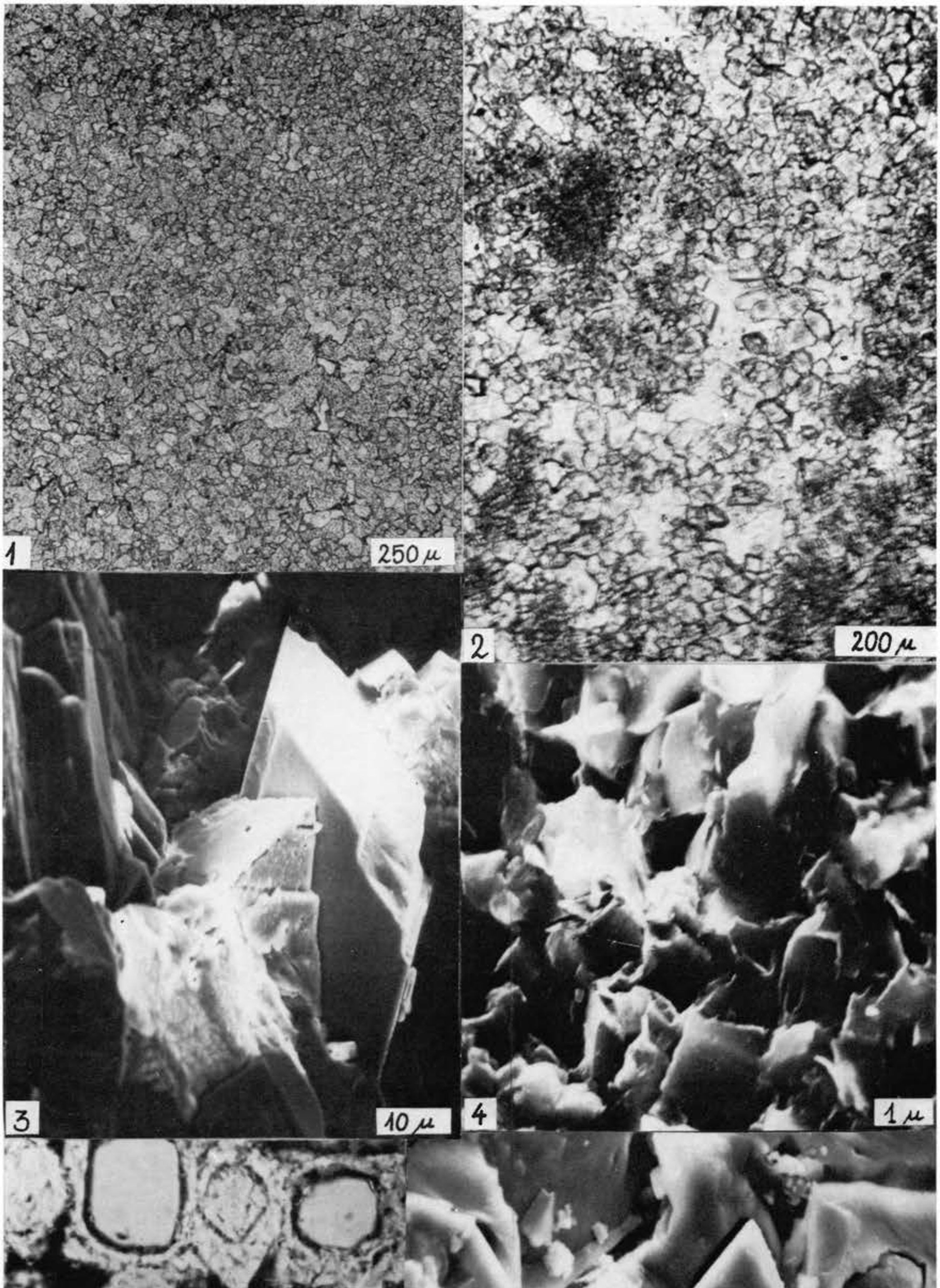
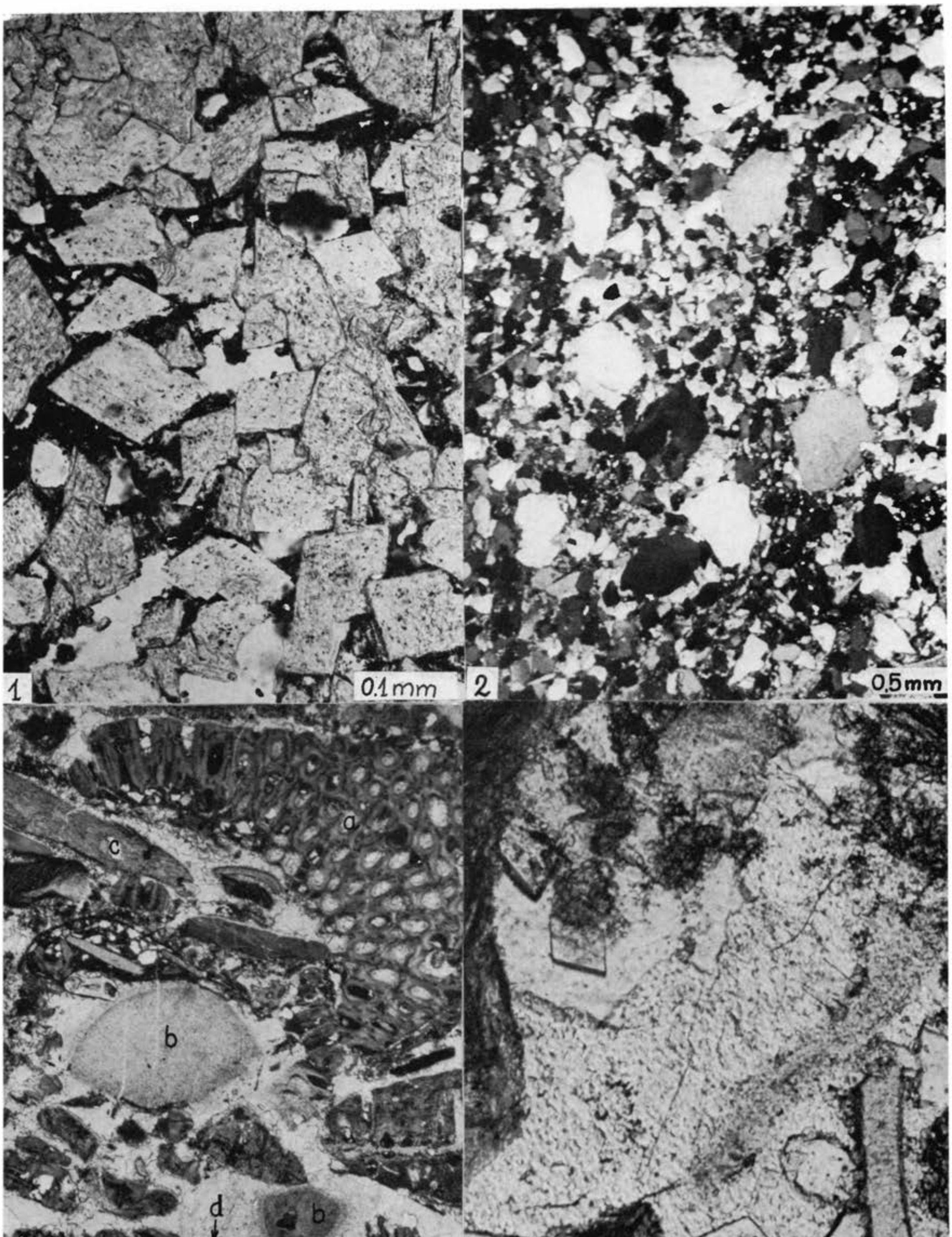

1
250 μ
2
200 μ
3
10 μ
4
1 μ
5
50μ
6
3μ

PLATE IV

1. Rhombs of dolomite present in pores of a very finely-crystalline dolomite. Fusulina Limestone, Kapp Dunér section, thin section K.D.1, plane polarized light.
2. Bimodal sand indicative of desert deflation flat environment. Quartzarenite, Spirifer Limestone, Hervigshamna section, thin section H.3; crossed nicols.
3. Biosparrudite. a – unaltered bryozoan skeleton: zoecia mostly filled with sparry calcite; b – echinoderm fragments; c – partly silicified brachiopod shells; d – a brachiopod spine. Note thin rims of bladed sparry calcite around fragments of fossils. Coarse equant sparry calcite constitutes the dominant variety of cement. Spirifer Limestone, Hervigshamna section, thin section H.7., plane polarized light.
4. Rhombs of limpid dolomite scattered throughout coarsely crystalline sparry calcite cement. Spirifer Limestone, Kapp Olsen section, thin section K.O.10a, plane polarized light.


1
0.1mm
2
0.5mm
a
c
b
d
b
b
c
3
1mm
4
100µ

Secondary Fe-spinel formation in red beds from the Wood Bay Formation, Svalbard

By Erik Halvorsen[1]

Contents

Abstract

A rock magnetic and palaeomagnetic study of some red beds from the Wood Bay Formation (northern Spitsbergen) reveals that secondary Fe-spinels commonly formed in these rocks during their history when subjected to moderate or high temperatures. Three different types of samples have been studied:

a) *Baked sandstone inclusions from a basaltic neck.* Measurements of saturation magnetization (J_s) versus temperature suggest magnetite or possibly maghemite as the secondary Fe-spinel phase. The magnetization directions from the inclusions are in agreement with those from the volcanic neck and the NRM intensities as well as low-field susceptibility is of similar magnitude in the two different rock types.

b) *Heated samples from a zone around the neck.* These samples showed that both secondarily formed Fe-spinels and remains of the original magnetic mineralogy contribute to the magnetic properties of these samples.

c) *Apparently 'unaltered' red sandstone samples.* These rocks seem to have become strongly remagnetized as well. This is evident from a comparison between the estimated secondary magnetization direction in the sandstones and the primary magnetization directions from the Mesozoic lavas in the area. Magnetic mineralogy characteristic for Fe-spinels was also dominating in these samples.

[1] Department of Geophysics, University of Bergen, Bergen, Norway.

Introduction

The Old Red Sandstone sedimentation in Spitsbergen consists of red or grey-green sandstones typically alternating with red siltstone. The existence of both coarse- and fine-grained beds of grey-green colour within the sequence of mainly red beds suggests that post-depositional reduction of ferric iron has taken place locally (FRIEND 1961). Thin section examination shows red pellicles surrounding many of the sediment grains being composed of numerous very small (up to 0.001 mm diametre) granules, probably haematite (FRIEND 1961). Angular flakes of opaque iron oxide are also found. The outer layer of the flakes appears to be composed of the same very fine haematite as the pellicles on the grains.

As part of a program to obtain more palaeomagnetic data from Spitsbergen the magnetization of red beds within the Wood Bay Formation (L. Devonian) has been studied. In a recent study of similar red beds from central Spitsbergen, STORETVEDT (1972) has suggested that the Upper Devonian phase of diastrophism in central Spitsbergen led to an extensive modification of the original magnetic record. Fe-rich spinels appear to have been formed from haematite, causing thermo-chemical secondary magnetization. The palaeomagnetic investigation of the Halvdanpiggen volcanic neck (HALVORSEN 1972), which intrudes the Wood Bay Formation in northern Spitsbergen, revealed that baked red sandstone inclusions had similar remanence properties as the basaltic rock. Ore microscope studies showed that the magnetic minerals in both types of samples were mainly Fe-rich spinels.

In addition to the study of the natural remanence of the red beds from the Wood Bay Formation, the present paper reports the results of a rock magnetic and magnetic fabric study of baked and heated red beds from the same formation. The baked samples are found as inclusions in the earlier mentioned Halvdanpiggen neck and the heated samples are collected close to the neck.

The sampled localities lie all within the Devonian graben which is bounded by faults running N-S (Fig. 1). In addition to the sequence of sediments the area is characterized by remnants of igneous activity of both late Mesozoic and Quarternary age (HOEL and HOLTEDAL 1911, HOEL 1914). Permian igneous activity is suggested from the palaeomagnetic pole position of the Halvdanpiggen neck (HALVORSEN 1972).

The field work was carried out in the summer season of 1970. Hand samples were collected in the field and the orientation was normally done by magnetic compass. Cylinders (19 $\times$ 19 mm) were then cut in the laboratory. The total error involved in field orientation, drilling and transformation of orientation is estimated to be in the range of 3 to 5 degrees.

The magnetization was measured by means of astatic magnetometers and thermal demagnetization was performed following the method by STORETVEDT et al. (1968). Saturation magnetization (J_S) versus temperature has been measured with a translation balance. The heatings were carried out in air in app-

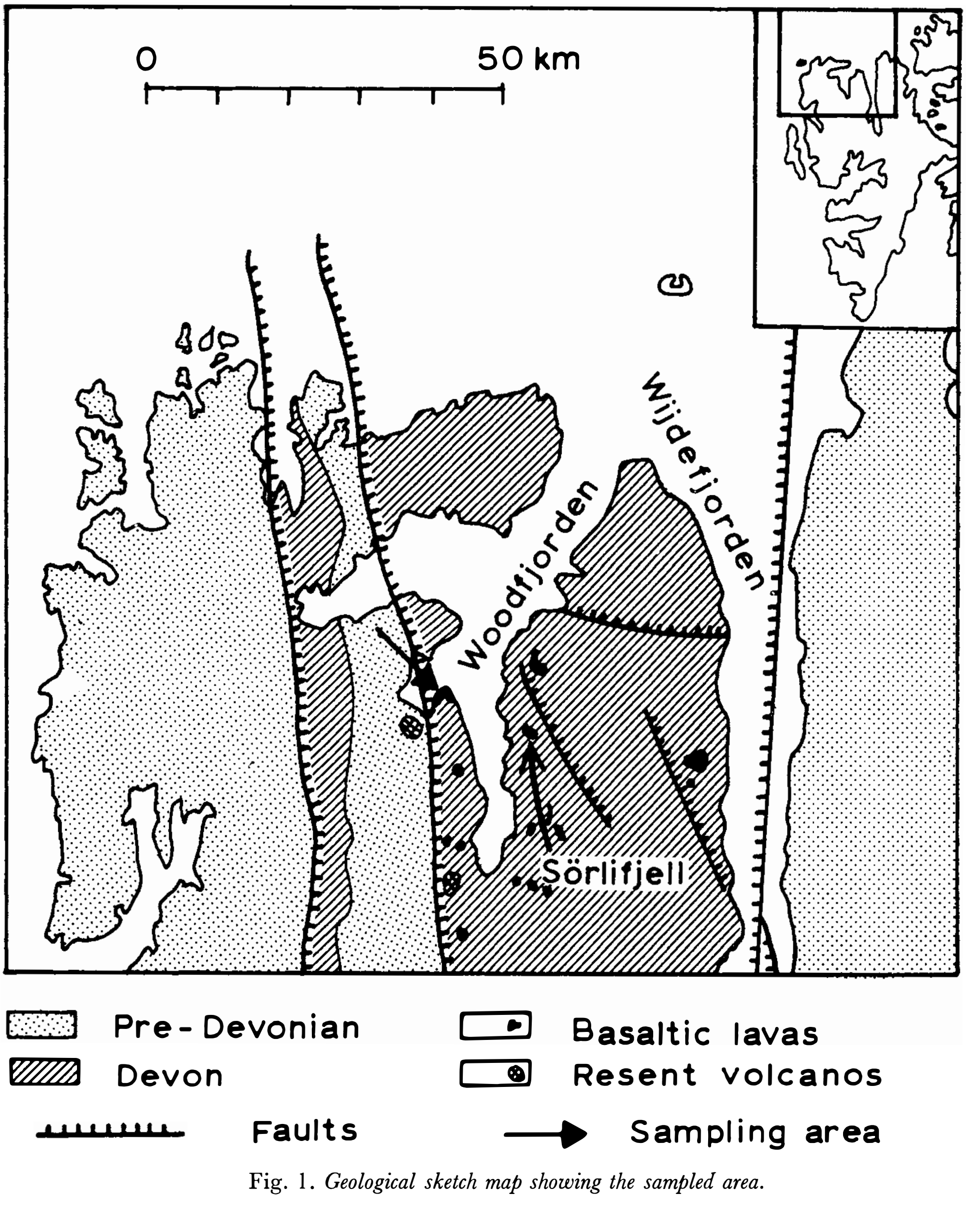


Fig. 1. *Geological sketch map showing the sampled area.*

lied field strengths varying between 5000 and 6500 Oe. Magnetic susceptibility anisotropy was measured on an AC-bridge as described by JELINEK (1973).

Experimental results

1. 'UNALTERED' RED SANDSTONE; NRM AND DEMAGNETIZATION

Altogether 25 hand samples representing a stratigraphic thickness of 250 metres have been investigated. The samples were collected from 12 sites evenly

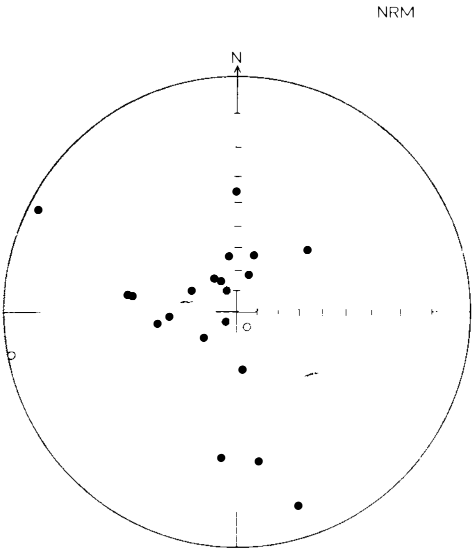


Fig. 2. *Directions of natural remanent magnetization of the Wood Bay Series with the postulated Devonian magnetization axis* (STORETVEDT *1972*). *Stereographic projection.*

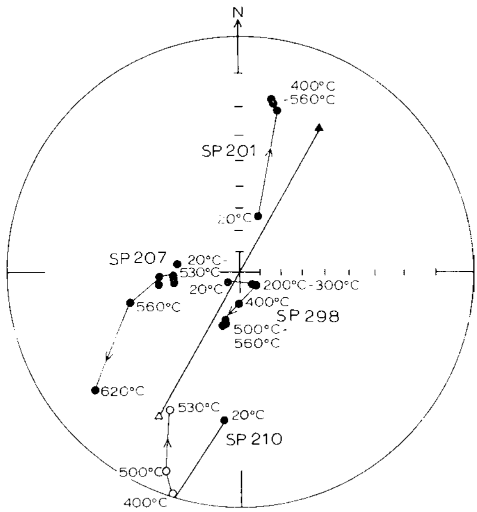


Fig. 3. *Direction of remanent magnetization as a function of temperature, stereographic projection.*

spaced in the sequence of beds studied. The red beds are relatively strongly magnetized. NRM intensities varied from 23.4×10^{-6}emu/cm^3 to 4.5×10^{-6} emu/cm^3 with a mean of 9.6×10^{-6}emu/cm^3. The directions of NRM are relatively well grouped with generally downward inclination (Fig. 2). However, the directions of magnetization do not agree with Devonian directions of Europe previously determined (STORETVEDT 1970, STORETVEDT and PETERSEN 1972). To test the magnetic stability one specimen from each sample was thermally demagnetized to progressively higher temperatures. Above 530–560°C increasing intensities occurred in most cases.

From the demagnetization studies two different magnetization axes are recognized: a steeply inclined one apparently of only normal polarity and a more shallow axis including both polarities. Typical examples of directional changes during demagnetization are plotted in Fig. 3. Samples SP 207 and SP 298 are examples of specimens which kept their steeply dipping magnetization rather unchanged when demagnetized to about 500°C. The suggested Devonian magnetization (cf. STORETVEDT 1972) are more pronounced in samples SP 201 and SP 210. The decay of NRM intensities showed blocking temperatures from 200°C to 600°C. At 500°C the remaining intensity varied between 4% and 55% of the original. On the whole, the thermal demagnetization characteristic of these rocks suggests that a spinel phase rather than haematite is the main remanence carrier. The scatter of the original directions (steep) increased on demagnetization as the relative importance of the Devonian magnetization became more pronounced. This is illustrated in Fig. 4 in which the magnetic remanence directions at 400°C are plotted together with

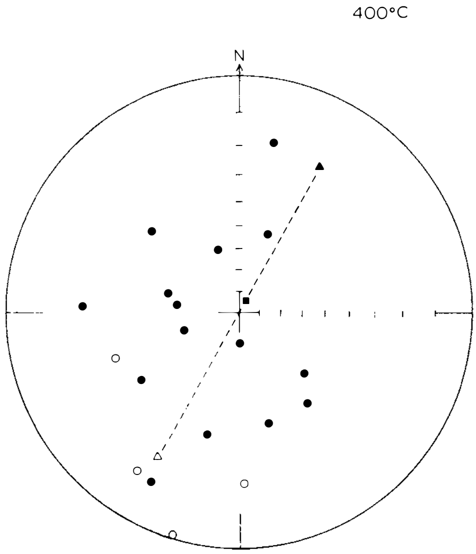


Fig. 4. *Direction of remanent magnetization at 400°C, stereographic projection.*

the postulated Devonian magnetization axis for Spitsbergen (STORETVEDT 1972). All samples revealed directional movement during the major part of the demagnetization spectrum, in particular at high temperature levels, making the isolation of the Devonian magnetization direction unsuccessful.

2. ALTERED (HEATED AND BAKED) RED SANDSTONES

a) magnetomineralogy

In order to study the magnetic minerals of the baked and heated red sandstone samples the change of saturation magnetization (J_S) versus temperature combined with microscopic studies of the opaques have been performed. In addition the low-field susceptibility was measured in an applied magnetic field

Table 1

Summary of results from the magnetomineralogical investigation

Sample No.	Suspect. $x10^{-4}$	Remanent int. $x10^{-4}emu/cm^3$	Curie temp. heating, °C	Curie temp. cooling, °C	Dist. from cont. m	Sample type
SP 58	4.71	43.83	600			Inclusion
61	3.89	15.15	565			—«—
63		26.34	585			—«—
74	5.18	52.02	590			—«—
75	4.19	46.29	545			—«—
65	5.29	2.13	600		0.3	Contact-sect.
66	3.24	0.80	610	575	0.4	—«—
68		0.04			40.0	—«—
77	0.27	0.03			50.0	—«—
78	0.24	0.03	580		50.0	—«—

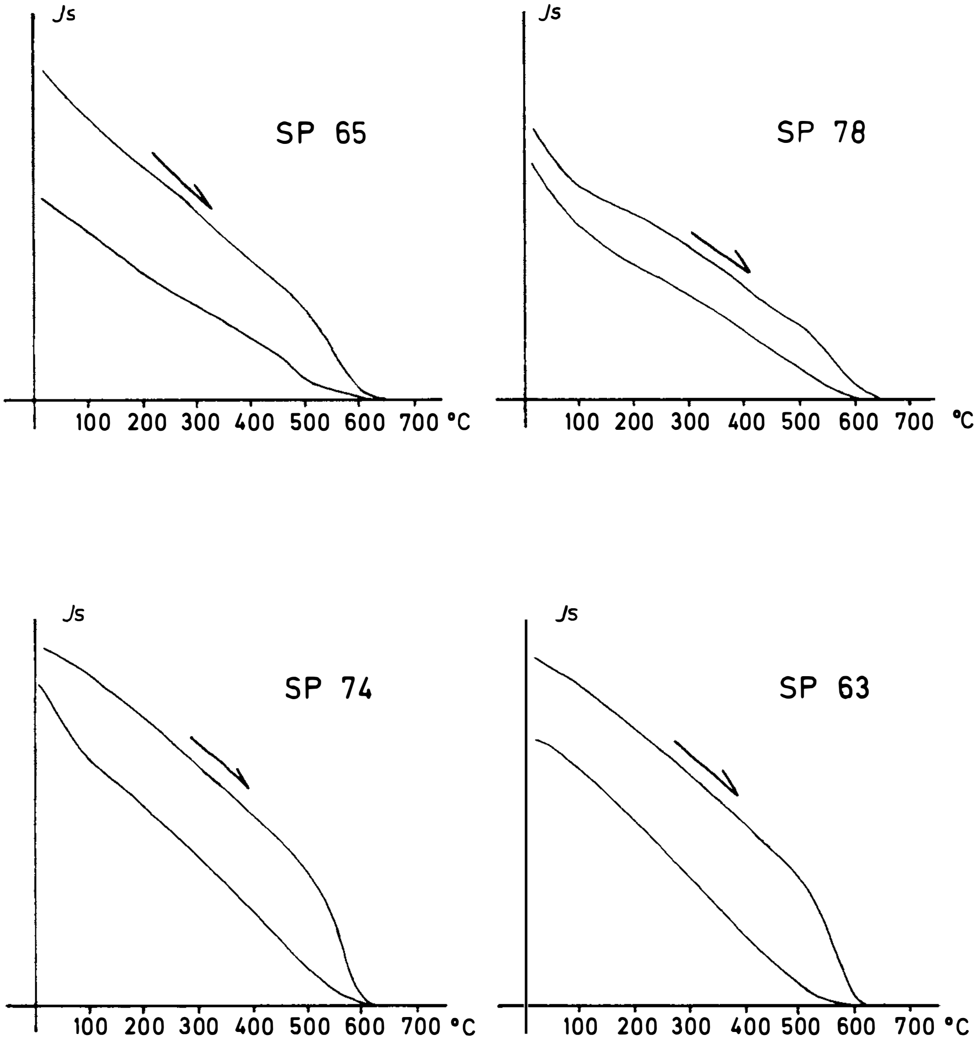


Fig. 5. *Saturation magnetization* (J_s) *versus temperature, altered (heated) red beds.*

of 1 Oe. The results of the investigation are summarized in Table 1, while Fig. 5 shows the change in saturation magnetization with temperature for selected samples. Samples SP 58, 61, 63, 74, and 75 are from inclusions, while samples 65, 66, 68, 77, and 78 are collected close to the neck (the distance from each sample to the neck is given in Table 1). The table also includes the intensity of NRM for the different samples.

Both the intensity of the NRM and the bulk susceptibility reveal a strong increase when going from sample SP 78 through the contact to the sandstone inclusions, the intensity of magnetization and the susceptibility of the sandstone inclusions being of comparable magnitude to that of the basaltic neck (HALVORSEN 1972). The most likely explanation of this increase is a reduction from a weak magnetic phase (haematite) to a stronger one (magnetite or perhaps maghemite-phase). However, the possibility that the strongly magnetic phase is derived from Fe-rich silicates or that the basic magma entered the inclusions and crystallized within them must be considered as a realistic possibility.

J_S-T measurements on unaltered sandstone gave little information about the magnetic phases present mainly because it was necessary to use a high magnetization field due to the low susceptibility (HALVORSEN, unpublished data). Thus, the resulting paramagnetism was able to overprint and distort the experimental evidence for any high temperature phase. The T_C's of the contact samples and sandstone inclusions were all found in the range 545–610°C, six of altogether eight samples had a T_C in the range 580–610°C. This observation together with the instability of this phase revealed by the cooling curve points to a maghemite (cation deficient spinel) as the principal magnetic constituent.

Recent investigations of the magnetic mineralogy of heated and unheated red sediments by STEPHENSON (1967), SCHWARZ (1969) and DUNLOP (1972) have shown that the formation of a strongly magnetic phase is a common result of heating red sediments in air. It is at present not clear whether this new magnetic phase originates in haematite or in a non-magnetic mineral.

The range of Curie temperatures found in this study agrees with those found by JOHNSON et al. (1972) in a study of spinel formation in haematite. They suggest that the strong magnetic phase may be magnetite or a metastable phase with maghemite structure. It is not clear to the present author whether their results based on synthetic haematite can be compared with the Spitsbergen red sandstones.

STEPHENSON (1967) found that the grain size of the new magnetic phase most probably lies in the single domain range. The microscopic investigation of the different red sandstone samples from Spitsbergen gave as result that the grain size was $<1\mu$ except for a few grains in the range 1–10μ. The small grain-size made a determination of the type of magnetic minerals impossible with our microscopes.

b) remanence properties

Thermal demagnetization has been applied on baked sandstone inclusions and on heated samples from near the contact between the sandstone and the neck. Fig. 6 plots the intensity decay as a function of temperature for selected samples. It must be remembered that the NRM intensity of the inclusions (sample SP 74) is about three orders of magnitude larger than that of sample SP 78 (see Table 1). Bearing this in mind it is seen in Fig. 6 that there is a gradual change from sample with a NRM decay similar to that of unaltered sandstones (cf. section 1) to the inclusions revealing a distinct blocking temperature interval from about 450 to 550°C. This change in decay of NRM is accompanied by an identical change in remanence direction from that of unaltered sandstones towards a more and more well defined group of reversely magnetized directions as shown in Fig. 7 for three typical samples. The direction of SP

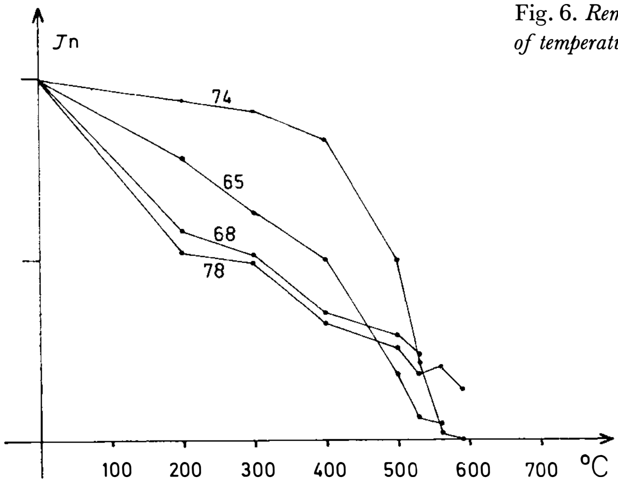


Fig. 6. *Remanent magnetic intensity as a function of temperature, altered (heated) red beds.*

74 is representing the direction found in the Halvdanpiggen neck (HALVORSEN 1972). Above 500°C the baked samples started to change direction against the opposite polarity, but the intensities of NRM at these high temperatures were too low for continued demagnetization to temperatures above 600°C. It is common at these high temperatures to observe increasing intensities with scattered magnetization directions probably due to mineralogical changes in the samples.

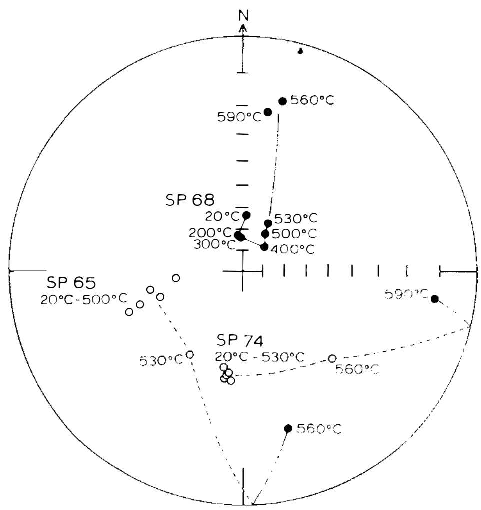


Fig. 7. *Direction of remanent magnetization as a function of temperature, altered (heated) red beds.*

c) magnetic fabric studies

The results of the measurements of magnetic susceptibility anisotropy are given in Table 2. The magnetic susceptibility measured in a weak magnetic field is a symmetric second-order tensor which can be expressed by means of the susceptibility ellipsoid. The shape and orientation of this ellipsoid depend on the preferred orientation of ferromagnetic minerals in the rock. Dimensional orientation of the grains is the major factor which influence the magnetic anisotropy if the ferromagnetic fraction consists of cubic minerals.

The shape of the ellipsoid can be expressed by means of the conveniently chosen ratio of the values of principal susceptibilities. In the present paper the following parameters are used to describe the anisotropy of susceptibility:

Table 2

Mean susceptibility and magnetic susceptibility anisotropy

Sample No.	km	P	L	F	E
SP 57	3.81	1.077	1.033	1.043	1.010
58	4.71	1.076	1.023	1.052	1.029
59	4.82	1.093	1.029	1.063	1.033
61	3.89	1.084	1.026	1.070	1.043
62	3.47	1.093	1.026	1.066	1.044
74	5.18	1.103	1.037	1.065	1.027
75	4.19	1.109	1.050	1.056	1.006
65	5.29	1.223	1.045	1.170	1.120
66	3.24	1.275	1.057	1.207	1.143
77	0.27	1.044	1.008	1.036	1.013
78	0.24	1.037	1.012	1.025	1.013

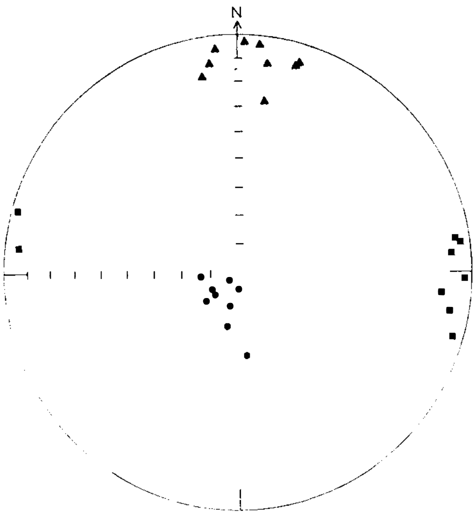
Explanation: k_m is in 10^{-4} c.g.s. units; P, L, F and E are the anisotropy factors (see text).

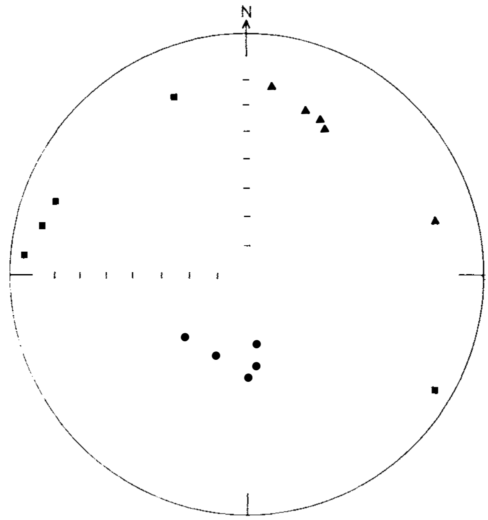
P, L, F and E. The total degree of preferred orientation of magnetic minerals may be inferred from NAGATA's (1961) anisotropy factor $P = K^{I}/K^{III}$, where K^{I} and K^{III} are the maximum and minimum susceptibilities respectively. The factor $L = K^{I}/K^{II}$ (K^{II} = intermediate susceptibility) called the magnetic lineation, characterizes the intensity of the linear—parallel orientation of "ferro"-magnetic minerals in a rock. On the other hand, the magnetic foliation $F = K^{II}/K^{III}$ expresses the degree of the planar parallel orientation of "ferro"-magnetic minerals.

In order to distinguish between predominantly oblate and predominantly prolate susceptibility ellipsoids and to find whether the magnetic lineation or foliation is the more intensively developed feature, the E-factor can be used, $E = (K^{II})^2/(K^{I}K^{III})$. If $E>1$ the ellipsoid is predominantly prolate and if $E<1$ the susceptibility ellipsoid is oblate. When $E = 1$ the intensities of both orientations are equal.

Table 2 shows that the P-factor varies from 1.077 to 1.109 for the inclusions and 1.275 to 1.037 from the contact samples. The susceptibility ellipsoids are prolate (the E-factor is always larger than 1), they exhibit a dominating magnetic foliation as seen from the large F-values. In the magnetic foliation plane the L-values show that there is a distinct difference between the K^{I} and K^{II} axes. Samples SP 65 and SP 66 show the highest values of nearly all the anisotropy factors.

The directional orientation of the K^{I}, K^{II} and K^{III} axes are shown in Fig. 8 (sandstone inclusion) and Fig. 9 (heated contact sandstones). In accordance with the anisotropy factor data, there is a good grouping of the K^{I}, K^{II} and K^{III} directions for the sandstone inclusions. Minimum susceptibility is almost verti-





▲ = *maximum susceptibility directions;*
■ = *intermediate susceptibility direction;*
● = *minimum susceptibility direction.*

Fig. 8. *Direction of principal susceptibilities* (K^{I}, K^{II} *and* K^{III}) *from the baked red sandstone inclusions. Equal area projection, lower hemisphere.*

Fig. 9. *Directions of principal susceptibilities* (K^{I}, K^{II} *and* K^{III}) *from the heated red beds.*

cal while the magnetic foliation plane is close to the horizontal. The maximum susceptibility directions lie in a northerly direction while the intermediate directions are trending E-W. A similar orientation is seen in the contact sandstone (Fig. 9) but here the magnetic foliation plane is dipping slightly to the south.

Discussion

The result of the present study is that the magnetization of the Wood Bay Formation in the area concerned constitute a two-axes system. The Devonian magnetization contributes significantly to the NRM only in a few samples while in the majority of the samples a steeply dipping normal component appears to play the dominating role. As the scatter of the directions show a minimum for the total NRM an average of these directions has been calculated; samples with an inclination of less than 30° was excluded in the compution since these directions were considered to contain a relatively large Devonian magnetization contribution. Seventeen samples remained and the mean direction for these samples is: D = 306°, I = 72° and α_{95} = 11° (statistics are after FISHER (1953)).

This mean direction is believed to be a reasonable approximation of the geomagnetic field at the time the secondary magnetization was impressed. A late Mesozoic or an even younger origin for this latter component is probable fiom the magnetization direction. However, the most likely cause of the secondary magnetization is probably the extensive volcanic activity which took place inside the Devonian graben in late Mesozoic times. Thus, a palaeomagnetic investigation of the Sørlifjell lava sequence (cf. Fig. 1) gave a primary magnetization direction of D = 334°, I = 77° and α_{95} = 3°. When the estimated direction for the steeply dipping magnetization in the Wood Bay Formation are compared with the Sørlifjell direction, no significant difference is found. It is reasonable to suggest therefore, that the red beds became remagnetized during the late Mesozoic as a result of heating associated with volcanic activity. Secondary magnetization in red beds caused by moderate heating over periods of the order 10^6 years and subsequent cooling to normal temperatures have been discussed by CHAMALAUN (1964) and BRIDEN (1965). Thermal demagnetization characteristics of the Wood Bay Formation red beds suggest that a spinel phase is the main carrier of magnetization. This together with relatively low blocking temperatures (200–600°C) make the investigated red beds quite susceptible to remagnetization processes such as viscous PTRM (CHAMALAUN 1964). The results of the investigation of the Spitsbergen red beds reveal that seconday Fe-spinel easily forms when the beds are heated to moderate temperatures. In the case of the central Spitsbergen samples the Upper Devonian tectonic activity may have been responsible for the rise in temperature (STORETVEDT 1972) while the Late Mesozoic magmatism most probably caused the major magnetic mineralogy changes for the samples in the present study. The change of remanence properties typical for sandstones to a remanence with properties comparable to that found in basaltic material was investigated in the baked and heated red beds in connection with the Halvdanpiggen neck. The baked samples showed magnetic properties indicative of magnetite or possibly stablized maghemite and with magnetization directions similar to that of the Halvdanpiggen neck (HALVORSEN 1972, this study). The contact zones show the transition in remanence intensity, direction and mineralogy from unaltered red beds to baked samples. The investigation of the Wood Bay Series clearly demonstrates the instability of the original magnetic mineralogy against heating.

The magnetic susceptibility anisotropy measurements also suggest a secondary magnetic fabric since the fabric of the inclusions are similar to those of the heated contact samples. Though the small number of samples does not allow us to draw stringent conclusions the similarity of the magnetic fabric indicates that the same stress pattern has acted on the inclusions and the contact samples. The intrusive activity was most probably connected with tectonism in the area. The Halvdanpiggen is dated as Permo-Carboniferous from palaeopole determination (HALVORSEN 1972). In Lower to Middle Carboniferous times quite strong earth-movements took place in Spitsbergen following the old Devonian fault lines (ORVIN 1940). These movements consisted in an elevation of blocks followed by erosion, the same uplift and subsequent erosion happened again in younger Cretaceous. Thus, it seems reasonable to suggest that the investigated strata originally was at a much larger depth in the crust, probably a few kilometres as can be estimated from the sediments being eroded away.

An axial compression of significant magnitude can explain the observation that the magnetic foliation plane is approximately horizontal. The orientation of the maximum and intermediate susceptibility axes in the magnetic foliation plane probably reflects the horizontal forces acting when the secondary minerals crystallized. The spatial orientation of these forces was probably determined by the faults which were running approximately N-S.

Acknowledgement

The author is indebted to Professor K. M. STORETVEDT for critical review of the manuscript and to Mr. K. BREYHOLTZ for valuable assistance with the measurements. Norsk Polarinstitutt is thanked for extensive assistance during the field work. Financial support for the Svalbard project has been provided by the Norwegian Research Council for Science and the Humanities.

References

BRIDEN, J. G., 1965: Ancient secondary magnetizations in rocks. *J. Geophys. Res.*, **70**, 5205–5221.

CHAMALAUN, E. H., 1964: Origin of the secondary magnetization of the Old Red Sandstones of the Anglo-Welsh Cuvette. *J. Geophys. Res.*, **69**, 4327–4337.

DUNLOP, D. J., 1972: Magnetic mineralogy of unheated and heated red sediments by coercivity spectrum analysis. *Geophys. J. R. astr. Soc.*, **27**, 37–55.

FISHER, R. A., 1953: Dispersion on a sphere. *Proc. R. Soc. Lond.* Ser. A, 217, 295–305.

FRIEND, P. F., 1961: The Devonian stratigraphy of north and central Vestspitsbergen. *Yorkshire Geol. Soc. Proc.*, **33**, 77–118.

HALVORSEN, E., 1972: A palaeomagnetic study of two volcanic formations from northern Spitsbergen. *Norsk Polarinstitutt Årbok* 1970, 70–75.

HOEL, A., 1914: Nouvelles observations sur le district volcanique du Spitsberg du nord. *Vid.Selsk. Skr. I Mat.-Nat. kl.* No. 9, Kristiania, 33.

HOEL, A. and O. HOLTEDAHL, 1911: Les nappes de lave, les volcans et les sources thermales dans les environs la Baie Wood. *Vid.Selsk. Skr. I Mat.-Nat. kl.* No. 8, Kristiania.

JELINEK, V., 1973: Precision A.C. bridge set for measuring magnetic susceptibility of rocks and its anisotropy. *Studia Geoph. et Geod.*, **17**, 36–48.

JOHNSON, H. P., H. KINOSHITA, and R. T. MERRILL, 1972: Spinel formation by heating haematite in air and water vapour. *Nature Phys. Sci.*, **239**, 151–152.

NAGATA, T., 1961: *Rock Magnetism.* Maruzen Co. Ltd., Tokyo.

ORVIN, A. K., 1940: Outline of the geological history of Spitsbergen. *Skr. Svalbard og Ishavet,* Nr. 78.

SANDAL, S. T. and E. HALVORSEN, 1973: Late mesozoic palaeomagnetism from Spitsbergen; implications for continental drift in the Arctic. *Phys. Earth Planet. Interiors.* **7**, 125–132.

SCHWARZ, E. J., 1969: Thermomagnetic analysis of some red beds. *Earth Planet. Sci. Lett.*, **5**, 333–338.

STEPHENSON, A., 1967: The effect of heat treatment on the magnetic properties of the Old Red Sandstone. *Geophys. J. R. astr. Soc.*, **13**, 425–440.

STORETVEDT, K. M., 1970: The devonian palaeomagnetic field for Europe. *Palaeogeophysics.* Academic Press., 247–252.

— 1972. Old Red Sandstone palaeomagnetism of central Spitsbergen and the Upper Devonian (Svalbardian) phase of deformation. *Norsk Polarinstitutt Årbok* 1970, 59–69.

STORETVEDT, K. M., E. HALVORSEN, and G. GJELLESTAD, 1968: Thermal analysis of the natural remanent magnetism of some Upper Silurian Red Sandstone in the Oslo region. *Tectonophys.*, **5**, 413–426.

STORETVEDT, K. M. and N. PETERSEN, 1972: Palaeomagnetic properties of the Middle-Upper Devonian volcanics of the Orkney Islands. *Earth Planet. Sci. Lett.*, **14**, 269–278.

Magnetic profiling over Svalbard and surrounding shelf areas[1]

By KNUT ÅM[2]

Contents

Abstract

Airborne and shipborne magnetic measurements by Norges Geologiske Undersøkelse and Norsk Polarinstitutt carried out in 1970, together with other available magnetic measurements, are presented and interpreted.

An interpretation in terms of depth to magnetic basement reveals that the sediments are generally thicker than 4 km over a large area between Bjørnøya, Spitsbergen, Edgeøya, and Hopen. There are also up to 4 km of sediments on the shelf north of Spitsbergen. Other important results are that Hopen lies on a basement uplift, that the basement ridge along the western coast of Spitsbergen continues towards Bjørnøya, that Prins Karls Forland forms a horst, and that it is possible to trace a northward continuation of the Wijdefjord fault and the Forlandsundet graben.

Introduction

Svalbard comprises the islands between longitudes 10°–35°E and latitudes 74°–81°N (Fig. 1). The archipelago is situated in the north-western part of the Barents-Kara shelf, and since much of the shelf is probably composed of practically undisturbed post-Devonian sediments, the Svalbard region is an interest-

[1] Publication No. 41 in NTNF's continental shelf project.

[2] Norges geologiske undersøkelse, 7000 Trondheim. Present address: Statens oljedirektorat, 4000 Stavanger.

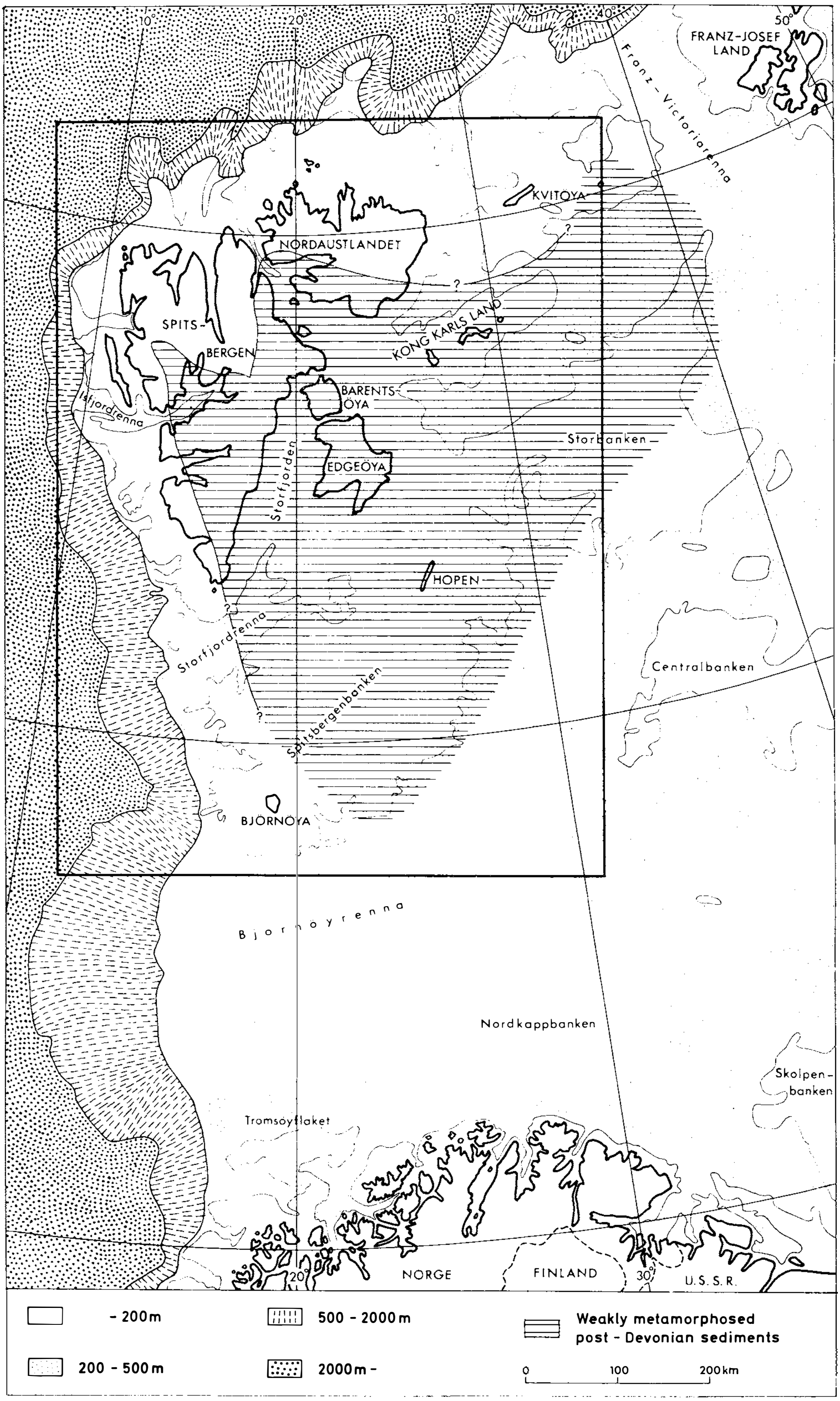


Fig. 1. *Location map, showing the main hydrographic features of the area.*

ing area in the world-wide search for oil and gas. Prospecting for oil in Svalbard in fact dates back to the early twenties (NAGY 1965), but up to 1960 economic geological work has largely been concentrated on coal deposits. Recent oil exploration in Arctic Canada, Alaska and Russia has, however, also resulted in an increased interest in other Arctic areas. Discussion concerning possible oil accumulations in and around Svalbard was therefore taken up again in 1960, and exploration activities have steadily increased since then.

From 1969 to 1973 all exploration of the Norwegian continental shelf north of 62°N has been coordinated by the Continental Shelf Division of the Royal Norwegian Council for Scientific and Industrial Research (NTNFK). Most of the activities have been concentrated south of 71°30′N, but in 1970 NTNFK also decided to do some geophysical reconnaissance work in the Svalbard region. As a part of this project 15 east-west trending aeromagnetic profiles were planned between Bjørnøya and Sjuøyane. Ten of these were flown by Norges Geologiske Undersøkelse, while the remaining profiles were measured with shipborne instruments by Norsk Polarinstitutt.

Although geomagnetic observations are known from Svalbard as far back as the 16th century (LUNDQUIST 1957), only a few systematic magnetometer surveys have been carried out. All the existing data belong to prospecting companies, except for some N-S trending aeromagnetic profiles flown by the U.S. Naval Oceanographic Office in 1963 (Project MAGNET, track numbers 637 and 638) and by the Dominion Observatory in 1965 (HAINES et al. 1970; flight numbers 30, 35, and 38). The main magnetic features of Svalbard are therefore practically unknown, and in order to correlate the magnetic results with known geological features several profiles were also flown across the land areas of Svalbard. Both the geology of Svalbard and the magnetic properties of its rocks are well documented (ORVIN 1940; KURININ 1965), thus providing a relatively firm base for a correlation between the magnetic anomalies and the geology.

Acquisition and presentation of data

Norges Geologiske Undersøkelse (NGU) measured 10 aeromagnetic "profiles" trending east-west across Svalbard from 19 to 25 April, 1970 (Fig. 2). A total of 14,000 line kilometers were measured. The two southernmost profiles were measured at an altitude of 450 m, while the rest of the profiles were flown at 1800 m above sea level. The three N-S trending profiles between Spitsbergen and Bjørnøya were flown on 11, 17 and 25 April at an altitude of 450 m. The measurements were carried out with a Varian 4947A proton magnetometer measuring the total magnetic intensity once per second with an accuracy of 1γ. The observed data were continuously recorded on an Ultralette strip chart analog recorder. The navigation over land was aided by accurate topographical maps produced by Norsk Polarinstitutt, resulting in a positional error of less

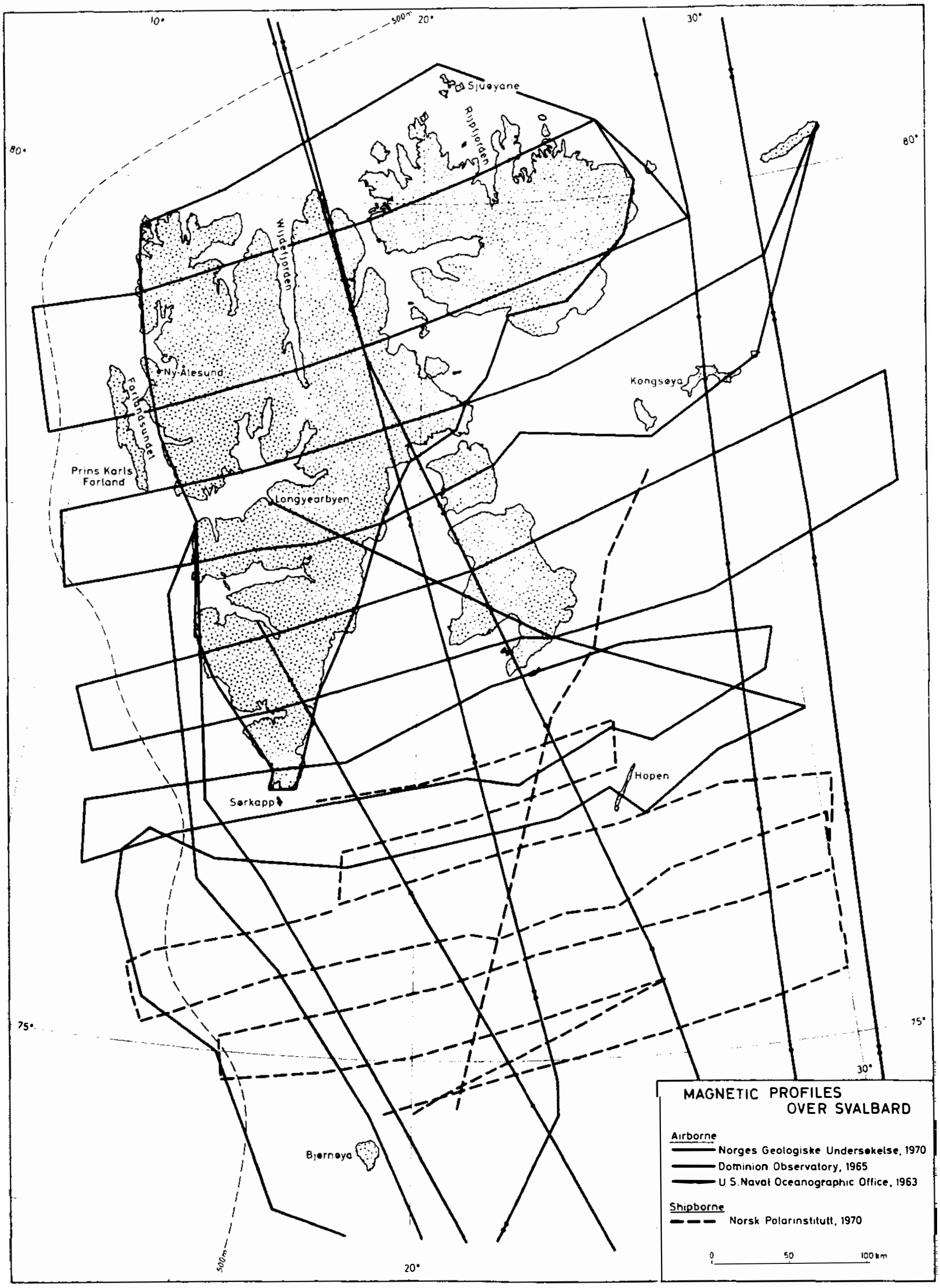


Fig. 2. *Position of airborne and shipborne magnetic profiles in the Svalbard region.*

than 2 km. Over the sea areas a magnetic compass, directional gyro and a Loran A and Consol receiver were used. The magnetic compass is not very effective at these latitudes, however, and the gyro could therefore not be properly adjusted. The Loran A and Consol navigation was also rather poor, and the maximum positional error is thought to be nearly 10 km in the sea-covered areas.

Magnetic conditions are generally bad in arctic regions, with frequent magnetic storms and practically no quiet periods. However, continuous magnetic observations carried out by Nordlysobservatoriet at Ny-Ålesund from the first half of April 1970, showed that the magnetic conditions would generally be fairly good between 12.00 and 19.00 hrs. The aeromagnetic measurements were therefore confined to this time of the day. In addition, the magnetic intensity was continuously recorded with a Varian M-50 proton magnetometer stationed at the flight-base outside Longyearbyen, but because the diurnal fluctuations of the magnetic field can be expected to change rapidly within short distances, no attempt was made to use the registrations from the stationary magnetometer to correct the airborne measurements for diurnals. Large fluctuations at the flight-base were, however, taken as an indication of unstable conditions in the area as a whole, and this resulted in two profiles having to be reflown under quieter conditions. Strangely enough, the remeasured profiles turned out to be practically identical to the profiles flown under "stormy" conditions. Very little sign was seen of the short wavelength fluctuations observed at the flight-base, but discrepanices with 30–60 minutes wavelength were found between the profiles. These variations did not seriously affect the form of the anomalies, and they showed only a slight resemblance to the broader variations observed at Longyearbyen. It is therefore felt that most of the aeromagnetic anomalies which have been observed in the Svalbard region are real and due to geological causes.

The analog records were digitized and the profiles redrawn in such a way that they could be placed directly on a map of the area. After a visual inspection of the profiles, a convenient and individual, linear, regional magnetic field was removed from each of the profiles. The residual magnetic intensity profiles were then drawn directly on a simplified geological map of the area (Fig. 3). Because of the wide spacing of the profiles and the lack of adequate control with diurnal magnetic variations, no attempt was made to produce a magnetic contour map of the area.

Largely because of navigational problems, five of the seven profiles originally planned between Bjørnøya and Spitsbergen were omitted by NGU. These profiles were measured with a shipborne magnetometer operated by Norsk Polarinstitutt onboard O/S "Senja" from 25 July to 31 August 1970. A total of around 5,000 line kilometres were measured. The measurements were carried out with a Geometrics G-801 proton magnetometer measuring the total magnetic intensity once per second with an accuracy of 1γ. The observed data were continuously recorded on a Hewlett-Packard strip chart analog recorder. For navigation a Decca Hi-Fix system was used, with slaves at Bjørnøya and Sørkapp. The system works at 1.9 MHz and the distance between lanes is approximately 80 m. This gives an excellent positional accuracy, but in spite of this the diurnal variations in magnetic intensity can, of course, render actual magnetometer readings almost useless. The magnetic conditions are known to

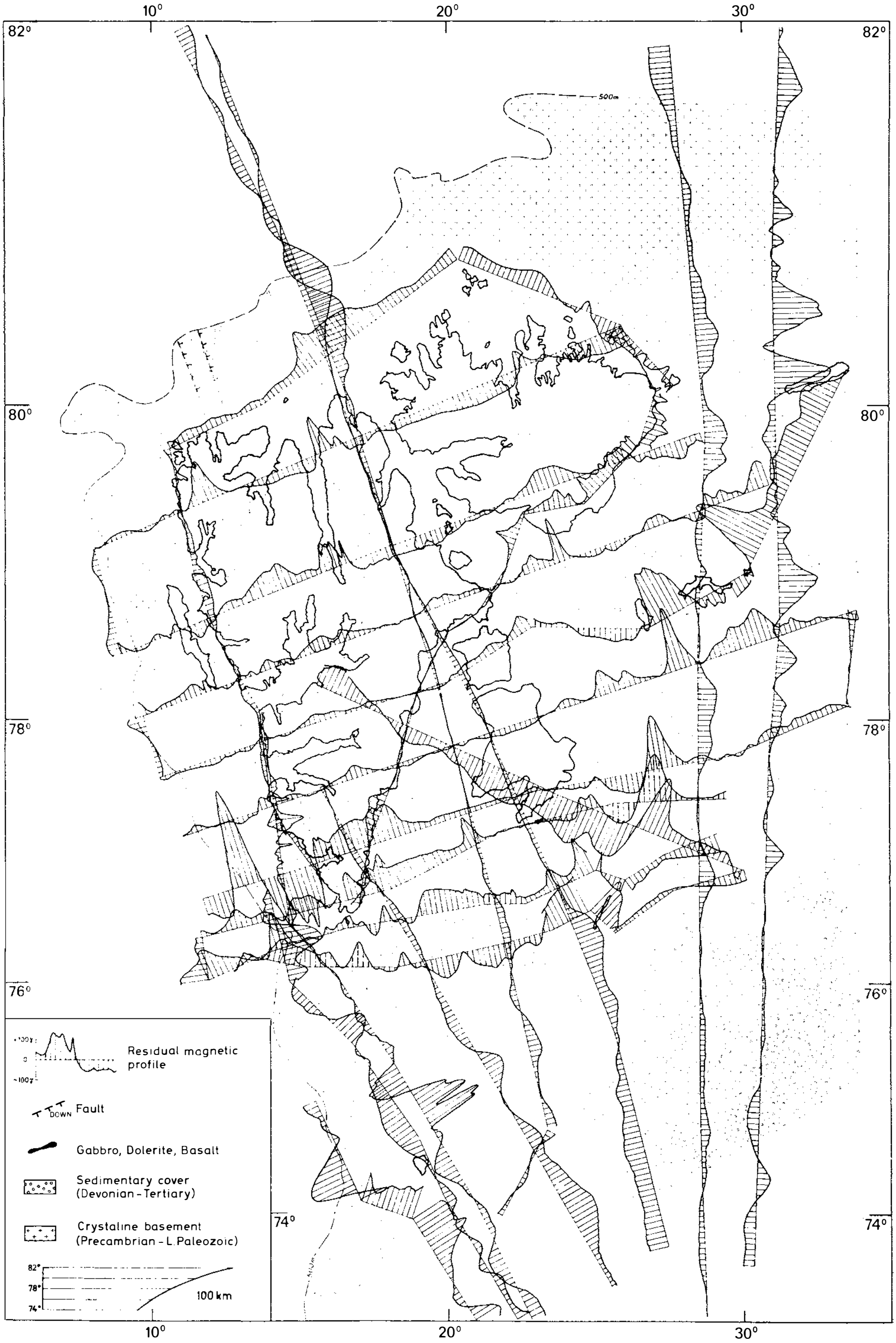


Fig. 3. *Residual aeromagnetic profiles superimposed on simplified geology. Mercator projection.*

be especially bad at night, and since the magnetic field has been measured continuously, night and day, the records can be expected to be highly contaminated with diurnal variations. This is, in fact, clearly seen in the records, which contain much noise and lots of doubtful anomalies. Some of the worst periods can be correlated with magnetic storms recorded by Nordlysobservatoriet at Bjørnøya, but generally a correlation with the records from Bjørnøya cannot be detected. In spite of the poor quality, the shipborne magnetometer records have been analysed and interpreted in the usual way together with the airborne data. It has not, however, been found worthwhile to digitize the shipborne records and present them together with the airborne profiles in Fig. 3.

As a part of Project MAGNET, the U.S. Naval Oceanographic Office measured two airborne magnetic profiles over Svalbard (Fig. 2). The westernmost profile (Track 637) was flown on 10 January 1963 at an altitude of 4,250 m in the southern part and 3,500 m in the northern part of the profile. The eastern profile (Track 638) was measured on 10 April 1963 at an altitude of 2,500 m above sea level. The measurements were carried out with a fluxgate magnetometer; the Naval Ordnance Laboratory Vector Airborne Magnetometer (VAM-2). The observed data were recorded on continuous curvilinear analog strip charts, and microfilm copies of the total magnetic intensity analog traces were available from USNOO together with positional and other data. The location of the tracks was primarily determinded by celestial navigation, and the maximum positional error is thought to be around 10 km. The analog records (microfilms) were digitized at NGU, a visual regional magnetic field was removed and the residual magnetic profiles were drawn at an appropriate scale so that they could be placed directly on a map of the area (Fig. 3).

In connection with a magnetic survey of the Nordic countries and Greenland, the Dominion Observatory measured three profiles over Svalbard (Fig. 2). The two westernmost profiles (Flights 30 and 35) were flown on 1 and 8 November 1965 at an altitude of 5,000 m. The eastern profile (Flight 38) was measured on 11 November 1965 at an altitude of 5,350 m above sea level. The measurements were carried out with a Barringer AM-101A proton magnetometer, which recorded the total magnetic intensity once per second. The residual magnetic field data, corrected for aircraft fields, were available from the Dominion Observatory as half-minute averages on digital magnetic tape, and with a maximum position error of 10 km. The residual magnetic profiles were drawn at an appropriate scale by NGU, and they are presented, together with all the other aeromagnetic profiles, on a simplified geological map of the area in Fig. 3. The geology is based on data from Norsk Polarinstitutt except for the basement in the vicinity of Bjørnøya which has been taken from ATLASOV (1964).

Interpretation

There is evidently no lack of magnetic anomalies in the Svalbard region, and a more detailed magnetic mapping of the area would probably be most fruitful. Because of the wide spacing of the profiles and the lack of adequate control with diurnal magnetic variations, it is not justifiable to try to determine strike directions and similar structural features from the data. However, some features are showing up so clearly that they deserve to be treated in some detail; but first of all the magnetic properties of the Svalbard rocks will be discussed.

Magnetic properties

Susceptibility measurements on 2,800 rock samples (KURININ 1965) have shown that the younger sediments of the region are practically non-magnetic. Exceptions, e.g. in the vicinity of Longyearbyen, could at best give rise to anomalies with amplitudes of a few tens of gammas. 250 measurements show that the dolerites are generally strongly magnetized, and large masses of such rock could give rise to 500–1000γ anomalies. Susceptibility values from the basement are somewhat sparse, but measurements on 250 samples from the sedimentary part show that the complex is generally non-magnetic. Two samples do, however, indicate the possibility of sedimentary material in the basement being capable of producing 300γ anomalies. The igneous part of the basement (200 samples) is also only weakly magnetic, but some of the granites could produce 100γ anomalies. This means that the anomalous magnetic intensities measured in the area are well within reasonable limits, as judged from susceptibility measurements.

Magnetic anomalies (*Fig. 3*)

The susceptibility measurements mentioned above show that the stronger anomalies found over the sediment covered areas are probably due to large masses of doleritic or gabbroic material. It should be noted, however, that where the profiles cross areas with such material at the surface, there are almost no magnetic effects seen in the records. This indicates that the doleritic and gabbroic intrusions seen at the surface are relatively small.

The 750γ anomaly west of Sørkapp (76°15′N, 13°E) is probably due to a large body extending vertically downwards from a depth of approximately 3.5 km below sea-level. The width of the body would have to be approximately 16 km and the apparent susceptibility contrast at least 0.003 cgs depending on the strike extent. This is higher than any of the values measured by KURININ (1965), but it is by no means unreasonable for gabbroic material. It can of course also be explained by the observed susceptibility values, if there is a moderate remanent contribution to the magnetization.

The pronounced anomalies (300–400γ) detected on three profiles NNE of Hopen (77°30′N, 27°E) are most likely caused by a common body situated approximately 3 km below sea level, and similar in composition to the body west of Sørkapp. The form of the anomalies reveals that if no abnormal remanence is involved the body is probably fairly flat-lying, dipping only 30° towards the east; it would have to be 15 km wide, and to have an apparent susceptibility of 0.0015 cgs. The strike of the body can be seen to be slightly east of north. If this trend is followed towards the north, a similar anomaly (due to a shallower and steeper body) is found in the next profile (78°20'N, 28°E), and further north it runs into a NNE-trending fault at Kongsøya (ORVIN 1940). This prominent magnetic trend could well represent a major fracture zone with gabbroic intrusions. The probable presence of gabbroic material at depth is supported by the occurence of basalts at the surface.

The second northernmost profile shows three distinct anomalies with amplitudes around 200γ. The westernmost anomaly (79°25'N, 12°E) is probably associated with the socalled "red granites" of this area. The susceptibility values reported by KURININ (1965) for these granites are too small, but modal analyses (HJELLE 1966) indicate that there is enough magnetite in the rock to produce the anomaly in question. (The magnetic susceptibility of a rock is due almost exclusively to magnetite, and for low magnetite contents the dependence is nearly linear, i.e. the susceptibility is between 0.0025 and 0.0030 times the volume per cent of magnetite in the rock.)

The anomaly in the middle of this profile (79°40'N, 15°30'E) is evidently related in some way to the large fault in Wijdefjorden. As a similar anomaly is found on the northernmost profile (80°10'N, 15°E) the existence and position of a northward continuation of the fault can be inferred. The fault itself cannot be responsible for this anomaly. The anomalous body is evidently dipping eastwards and cannot be situated far from the surface, if it is not actually cropping out. The anomaly is therefore most likely due to the amphibolites in the Harkerbreen Group of the area shown to be of volcanic origin (HARLAND et al. 1966) The corresponding anomaly to the south (79°N, 16°E) has a somewhat different form. It indicates that there are probably two minor faults and that the main fault is running west of Wijdefjorden in this area, as depicted by ORVIN (1940). It does not, however, indicate an eastward dip for the causative body but rather the opposite. The Wijdefjord fault can also be traced in the anomaly picture further south, but there is no significant anomaly connected directly with the fault itself.

The anomaly to the east (80°10'N, 22°30'E) occurs over the Rijpfjorden granite. Modal analyses (HJELLE 1966) indicate that the granite contains too little magnetite to be able to produce the anomaly, and susceptibility measurements on 5 rock samples (supplied by AUDUN HJELLE) confirm that the susceptibility of the granite is very low (all samples below $75 \cdot 10^{-6}$c.g.s.). If the source of the anomaly is not found in the granite, it must be sought in a very shallow layer dipping gently towards the east, implying that the granite is very thin. The anomaly is very similar to the anomaly in Wijdefjorden, and it is tempting to suggest that the causes are the same and that there is a major fault (with downthrow to the west) in both fjords. Although recent geological work around

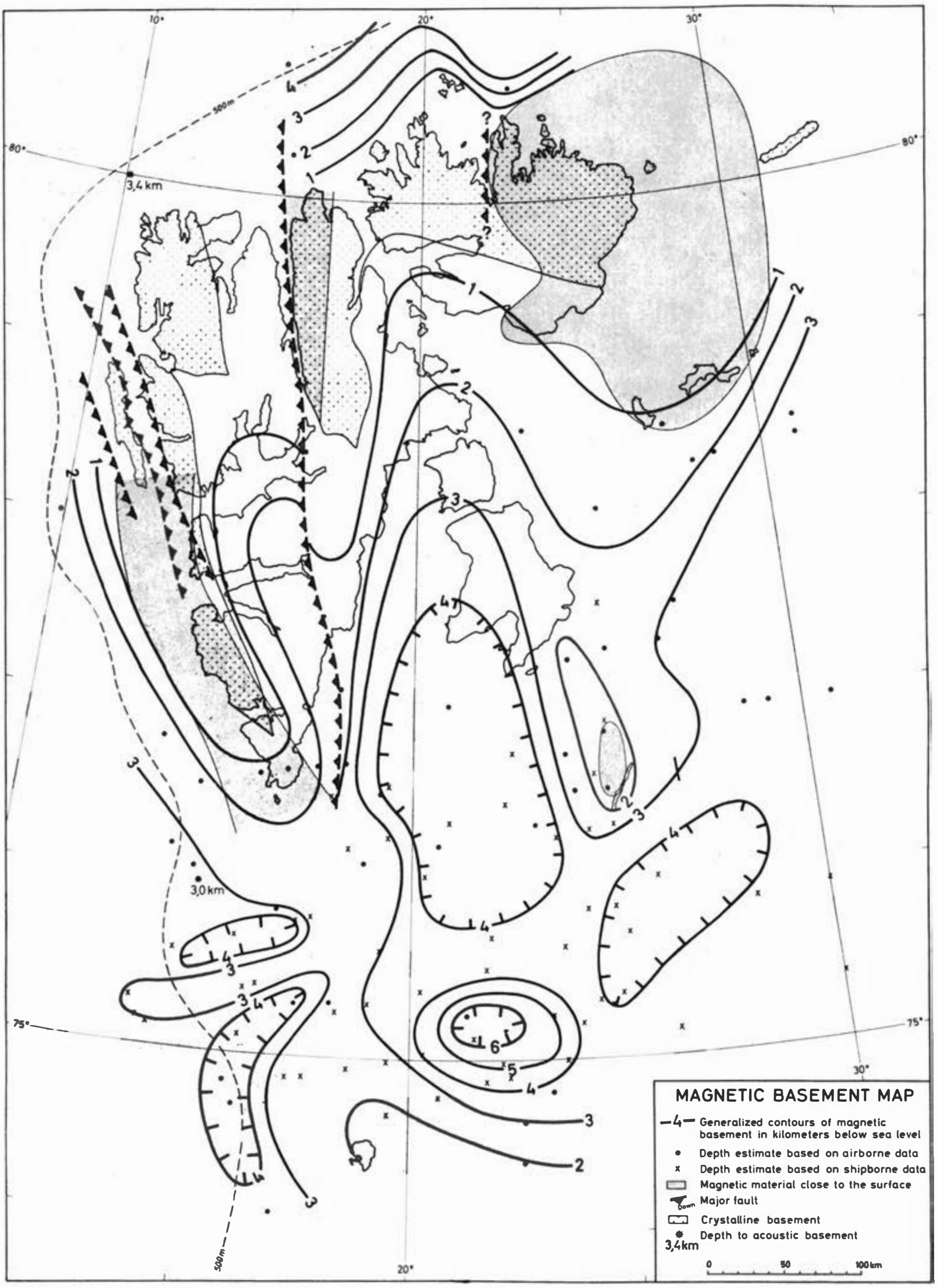


Fig. 4. *Interpretation map giving the main geological results of the present work.*

Rijpfjorden (Flood et al. 1969) does not support such an interpretation, a tentative fault has been drawn in Fig. 4.

The Forlandsundet graben shows up as a distinct magnetic low in one of the profiles (78°40'N, 11°30'E). If this is not mere coincidence the graben can be traced northwards at least as far as 79°20′N, whereas its continuation towards the south does not stand out so clearly.

The two profiles crossing Forlandsundet show a sharp cut in the anomaly to the west of Prins Karls Forland. This feature indicates a considerable downthrow to the west, meaning that Prins Karls Forland is probably situated upon a horst-like structure. A fault line to the west of Prins Karls Forland has also been suggested earlier (HOLTEDAHL 1937) based on the submarine topography.

Magnetic basement

It is well known that (aero)magnetic surveys over sedimentary basins are very useful for the determination of a general picture of the basement surface. Such interpretations in terms of depth to magnetic basement are generally found to be in reasonably good agreement with reality.

The depth determinations are based on two fundamental facts: 1) From the form of a magnetic anomaly it is possible to calculate the depth to the top of the body causing the anomaly. 2) Significant magnetic anomalies are almost exclusively due to magnetization contrasts in the basement as the sedimentary cover is generally devoid of larger masses of magnetic material.

If it is further assumed that the magnetic bodies reach the surface of the crystalline basement, the depths to the tops of the anomalous bodies, found from a careful study of the anomalies, will give points on the basement surface. When such depths have been determined for all magnetic anomalies in an area, the results are critically examined before a generalized contouring of the basement surface is made, giving less weight to uncertain determinations and values differing too much from the others.

In the present case the interpretation has been made directly on the original magnetometer records by the use of characteristic points and distances in the anomaly curves. A review of various methods for manual interpretation of magnetic data by the use of characteristics has recently been published by ÅM (1972). To give a correct depth, the profile must be perpendicular to the strike of an anomaly. If not, a correction for the deviation has to be made in the estimated depth. This has not been possible in the present case, since very little is known about the strike of the anomalies. However, experience shows that this is generally not a serious limitation, and rough magnetic conditions together with poor navigation are likely to be the major sources of error.

The resulting contoured basement surface is presented in Fig. 4. Major faults and areas showing signs of magnetic material at or close to the surface, as well as deeper material, are also indicated. Around Hopen and Kongsøya this shallow-lying material is probably either basalt or doleritic dykes in the sediments. In areas where only shipborne measurements exist, it is impossible to tell whether there is shallow magnetic material or not. This is due to the heavy short-wavelength noise which is contained in most of the shipborne records, and which is impossible to distinguish from "shallow" anomalies. Before calculating depths it was necessary to carry out a considerable smoothing of the original shipborne records. Since this is a particularly subjective operation, the depth estimates which are based on shipborne data may contain large errors and they have therefore been given a special sign in Fig. 4.

Discussion

The interpretation map (Fig. 4) should be able to speak for itself and so only a few comments will be given.

The geological causes of the magnetic anomalies in the region are not known, and it is therefore impossible to tell exactly what the so-called "magnetic basement" really comprises. It must be stressed that the magnetic basement is not necessarily identical with the top of the Hecla Hoek. There are, for instance, thick sequences of non-magnetic sediments in the Hecla Hoek succession, and there can, of course, also be large magnetic intrusions in the younger (post-Hecla Hoek) sediments. It must also be remembered that the contouring of the magnetic basement surface is based only on a few depth points. Between these points little or nothing is actually known about the depth to the basement. Besides, the interpretation, especially of the shipborne measurements, may have been driven too far. The interpretation (Fig. 4) should be looked at with all these limitations in mind.

The "hole" in the basement north-east of Bjørnøya is very peculiar. The shipborne records are exceptionally smooth in this area, and the airborne and shipborne data yield exactly the same depth (6.7 km). Hence, there should be nothing wrong with the depth estimate itself, but it is, of course, possible that the anomalous body is situated at some depth below the top of the basement.

Hopen is seen to lie on a structural high. This structure coincides with a large magnetic body in the basement (Fig. 3), and it is tempting to suggest that the uplift is caused by an intrusive mass which is possibly also the source of the shallow magnetic material in the sediments. It should also be noticed that the basement ridge along the western coast of Spitsbergen continues towards Bjørnøya, and that this structure seems to be crossed by an east-west trending structure at approximately 75°30′N.

The basement outcrops south of Spitsbergen (Fig. 3) as indicated by ATLASOV (1964) have not been confirmed. However, the present data indicate basement uplifts in these areas. Of other geophysical results in the Svalbard region, only two seismic refraction profiles published by ELDHOLM & EWING (1971) are known. These profiles show depths to acoustic basement (5.10 and 4.45 km/sec to the south and north of Spitsbergen, respectively) which are in good agreement with the magnetic results, as can be seen in Fig. 4.

Acknowledgements

I thank JENØ NAGY (Norsk Polarinstitutt) for his help, interest and constructive suggestions and comments. This paper was originally planned as a joint paper by NAGY and myself.

DAVID ROBERTS (Norges Geologiske Undersøkelse) kindly corrected the English text.

References

ATLASOV, J. P. (ed.), 1964: *Tectonic map of the Arctic and Subarctic 1:5,000,000.* Ministry of Geology of the USSR.

ELDHOLM, O. & J. EWING, 1971: Marine geophysical survey in the southwestern Barents Sea. *J. Geophys. Res.* **76**, 3832–3841.

FLOOD, B., D. G. GEE, A. HJELLE, T. SIGGERUD, & T. S. WINSNES, 1969: The geology of Nordaustlandet, northern and central part. *Norsk Polarinstitutt Skrifter* Nr. 146, 141 pp.

HAINES, G. V., W. HANNAFORD, & P. H. SERSON, 1970: Magnetic anomaly maps of the Nordic countries and the Greenland and Norwegian Seas. *Publ. Dominion Obs.* **39** (5), 123–149.

HARLAND, W. B., R. H. WALLIS, & R. A. GAYER, 1966: A revision of the Lower Hecla Hoek succession in central North Spitsbergen and correlation elsewhere. *Geol. Mag.* **103**, 70–97.

HJELLE, A., 1966: The composition of some grantitic rocks from Svalbard. *Norsk Polarinstitutt Årbok* 1965, 7–30.

HOLTEDAHL, O., 1937: On fault lines indicated by the subamrine relief in the shelf area west of Spitsbergen. *Norsk geogr. Tidsskr.* **6**, 214–221.

KURININ, R. G., 1965: Plotnost i magnitnaja vospriimcivost gornych porod archipelaga Spicbergen. *In:* SOKOLOV, V. N. (ed.) *Materialy po geologii Spicbergena*, 276–284. Leningrad. (Norwegian translation by Norsk Polarinstitutt, Oslo.)

LUNDQUIST, K. Z., 1957: Magnetic observations in Svalbard 1596–1953. *Norsk Polarinstitutt Skrifter* Nr. 110, 34 pp.

NAGY, J., 1965: Oil exploration in Spitsbergen. *Polar Record* **12**, 703–708.

ORVIN, A. K., 1940: Outline of the geological history of Spitsbergen. *Skrifter om Svalbard og Ishavet* Nr. 78, 57 pp.

ÅM, K., 1972: The arbitrarily magnetized dyke: Interpretation by characteristics. *Geoexploration* **10**, 63–90.

Polar bear den surveys in Svalbard in 1973

(Учет берлог белых медведей на Свальбарде в 1972 г.)

By Thor Larsen

Contents

Abstract

Two field groups, each consisting of two men, carried out polar bear den surveys on Kongsøya and Svenskøya on Kong Karls Land between 15 March and 29 April, and 17 March and 28 April, respectively. On Kongsøya, 26 days were effective for observations. 49 dens were found, of which 19 were classified as maternity dens, six as temporary dens, while in 24 cases the den type could not be determined. On Svenskøya, 23 days were effective for observations. 16 dens were found, of which two were assumed to have been maternity dens, six to have been temporary dens, and eight were undetermined. 13 dens were dug out and described on both islands. Ice conditions cannot account for the low number of dens on Edgeøya and Barentsøya, and had not affected the number of dens on Kong Karls Land in 1972 and 1973. Most dens on Kong Karls Land were abandoned between mid-March and the last week of March 1973. An estimated 40 maternity dens can be found on Kong Karls Land in a normal year.

Аннотация

Две полевых партии, каждая из которых состояла из двух человек, произвели учет берлог белых медведей на островах Kongsøya (Королевском) и Svenskøya (Шведском) на архипелаге Kong Karls Land (Земля Короля Карла) соответственно с 15 марта по 29 апреля и с 17 марта по 28 апреля. На о. Королевском в течение 26 удобных для наблюдений дней было обнаружено 49 берлог, из которых 19 были определены как родильные, 6 как временные, тогда как в 24 случаях определение берложного типа представлялось невозможным. На о. Шведском в течение 23 удобных для наблюдений дней было встречено 16 берлог, из которых 2 предположительно служили родильными, 6 временными, а 8 оказались неопределимыми. На обоих островах было вырыто и описано 13 берлог. Незначительное число берлог на островах Edgeøya (Эдж) и Barentsøya (Баренца) не может объясняться ледовыми условиями, не влиявшими на число берлог на Земле Короля Карла в 1972–1973 гг. Большинство берлог на Земле Короля Карла было покинуто между серединой и последней недели марта в 1973 г. По подсчетам имеется около 40 родильных берлог на Земле Короля Карла в нормальном году.

Introduction

An effort was made in 1972 to estimate the abundance of polar bear (*Ursus maritimus*) dens in Svalbard. The purpose of this study was primarily to define the relative importance of various regions as denning areas for polar bears rather than to try to determine the absolute number of dens. The eastern and northern parts of Svalbard were surveyed repeatedly from the air and from the ground between 25 March and 13 May, and a total of 84 dens were found (LARSEN 1974).

Polar bear den surveys in 1973

The 1973 polar bear den surveys in Svalbard were concentrated on Kong Karls Land. The purpose was to try to determine the absolute number of dens on the islands, to distinguish between den types whenever possible, and to describe den sites and den constructions. Two field groups each consisting of

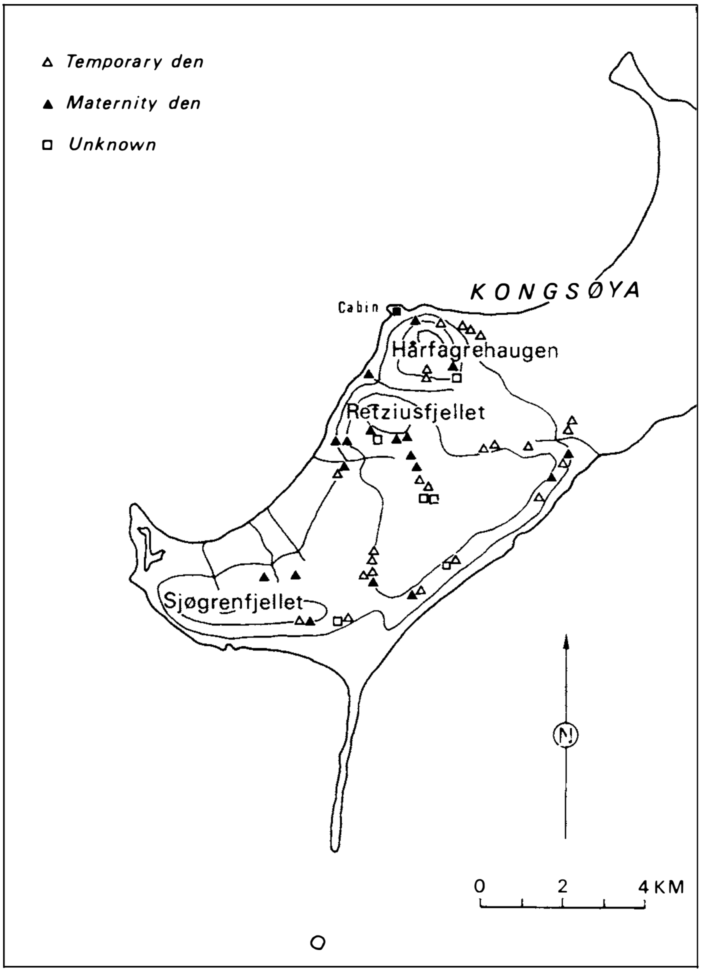


Fig. 1. *Polar bear dens recorded during ground surveys on Kongsøya, March and April 1973.* Берлоги белых медведей, учтенные во время наземных подсчетов на о-ве Kongsøya в марте-апреле 1973 г.

two men, carried out ground surveys on Kongsøya and Svenskøya between 15 March and 29 April, and between 17 March and 28 April, respectively. Each group surveyed the islands as often as possible in an effort to make absolute den counts. The dens found were marked with bamboo sticks and controlled repeatedly. Efforts were made to distinguish between maternity and temporary dens. When abandoned some dens were dug out and described. The field groups also made observations of single bears and family groups and their activities. Bad weather conditions hampered the work for both groups.

On Kongsøya 26 days were effective for observations, during which 49 dens were found. 46 dens were found between 16 and 26 March, 19 dens were classified as maternity dens and six as temporary dens, while in 24 cases, the den type could not be determined (Fig. 1). Of the unclassified dens, some were inaccessible, while storms had filled others with snow so that they could not be found afterwards. Five maternity dens and three temporary dens were dug out and described.

Den No. 4, located on the northern side of Hårfagrehaugen, 120 m above sea

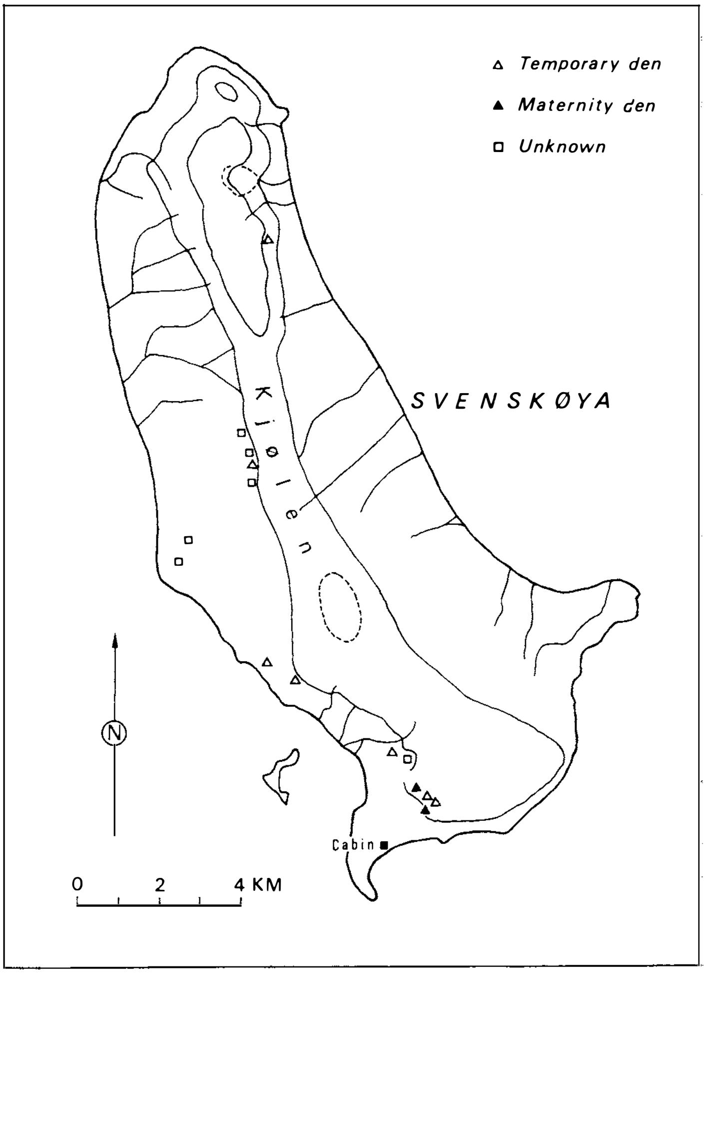
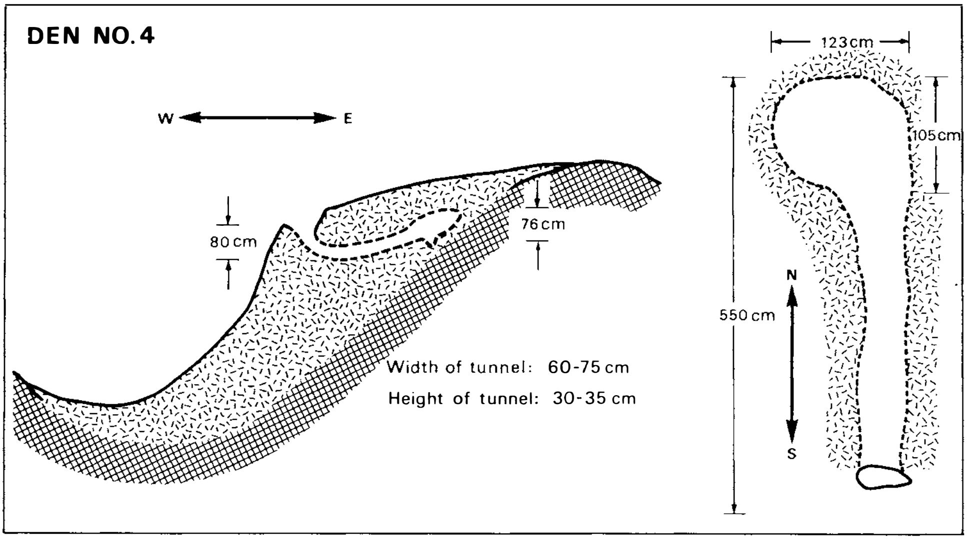


Fig. 2. *Polar bear dens recorded during ground surveys on Svenskøya, March and April 1973.* Берлоги белых медведей, учтенные во время наземных подсчетов на о-ве Svenskøya в марте-апреле 1973 г.



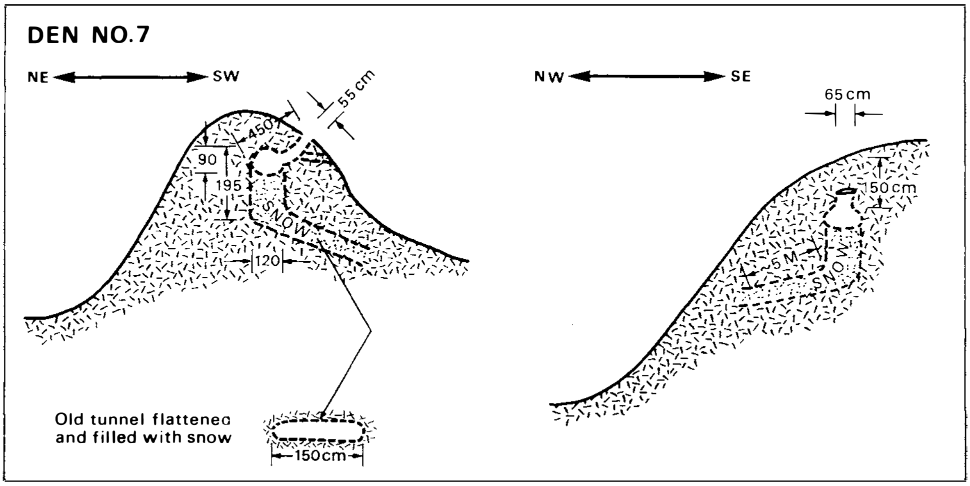
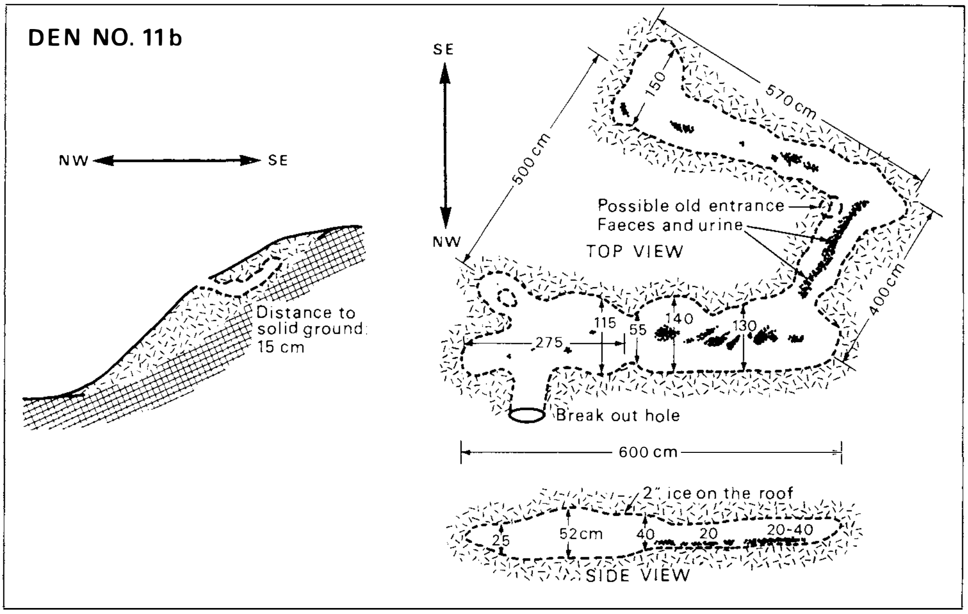


Fig. 3. *Cross section through polar bear den No. 4 on Kongsøya, March–April 1973.*
Поперечный разрез через берлогу белого медведя № 4 на о-ве Kongsøya в марте-апреле 1973 г.

Fig. 4. *Cross section through polar bear den No. 7 on Kongsøya, March–April 1973.*
Поперечный разрез через берлогу белого медведя № 7 на о-ве Kongsøya в марте-апреле 1973 г.

level, was abandoned by a female bear with one cub on 16 March and dug out on 13 April. The den consisted of an about 4.5 m long tunnel and a chamber with a diameter of about one metre. Snow had been dug out from the ceiling and packed on the floor. The floor and the snow outside the den had been sprinkled with urine. The digging from the ceiling seemed to have been done shortly before the den was abandoned (Fig. 3).

Den No. 7, located on the northern side of Retziusfjellet, 30 m above sea level and facing southwest, was discovered on 31 March when a hole was dug out



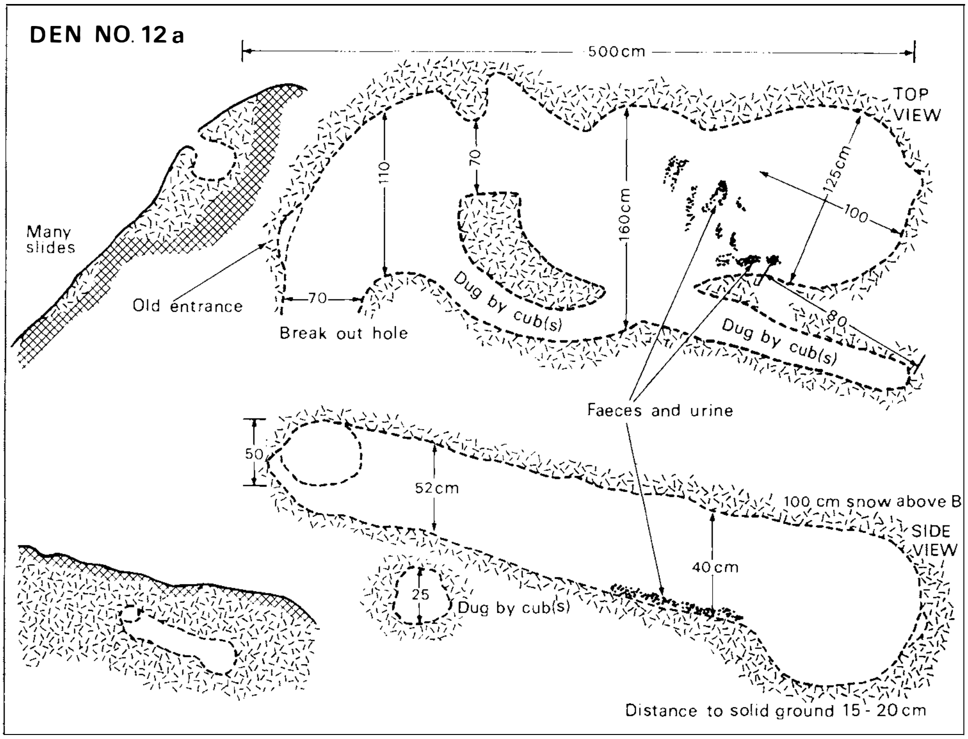


Fig. 5. *Cross section through polar bear den No. 11b on Kongsøya, March–April 1973.*
Поперечный разрез через берлогу белого медведя № 11b на о-ве Kongsøya в марте-апреле 1973 г.

Fig. 6. *Cross section through polar bear den No. 12a on Kongsøya, March–April 1973.*
Поперечный разрез через берлогу белого медведя № 12a на о-ве Kongsøya в марте-апреле 1973 г.

from the inside of the den. On 3 April, the female had been outside the den and on 10 or 11 April, she and her single cub had left it. When dug out on 13 April it was found that the den resembled den No. 4 in construction, but was sloping downwards. When the relatively clean floor was dug out, several other floors were found underneath, each with urine and old snow and ice. This indicates that the ceiling had been dug out several times during the winter, constantly elevating the den chamber. At the bottom, a tunnel packed with snow was found, and at the end of it, about half a kilo of faeces. The 4–5 m long snow-packed tunnel was probably the entrance which had been used when the den was dug in the previons autumn (Fig. 4).

Den No. 11b, located on the western side of Retziusfjellet and facing north-west, was found on 17 March when it had been abandoned by a female with one cub. It was dug out on 14 April. This den was an elaborate construction with a more than 15 m long tunnel and several chambers between. The den made several sharp bends. Much excrements and several urine holes were found (Fig. 5).

Den No. 12a was also found on the west side of Retziusfjellet, about 120 m above sea level, facing north. The den was found on 18 March and abandoned by a female with an unknown number of cubs between 13 and 15 April. The den was dug out on 16 April. The tunnel was more than five metres long, with one chamber at the end. The den had been dug alongside the ground. Faeces and urine were found here too, and several small tunnels had been dug by the cubs. The den was sloping downwards at an angle of about 15 degrees (Fig. 6).

Den No. 12 b was found close to 12 a on the same date. It was abandoned by a female with two cubs between 7 and 8 April and was dug out on 16 April. As den No. 12a, it was running alongside the ground. The tunnel which was more than four metres long, ended in a single chamber. The den was very clean at first inspection, but when the floor was dug out, faeces and urine were again found. The opening which had been used in the autumn was closed, and a new opening had been dug in the spring (Fig. 7).

Dens Nos. 21 A, B, and D were all found on the southeast side of Sjøgren-fjellet, about 110 m above sea level and facing southeast. They were found on 19 March and when dug out on 14 April, were found to be temporary dens. Dens A and B were only shallow pits in the snow, while den D consisted of a tunnel about three metres long. Faeces were not found and only small amounts of urine were found at den D. There was no chamber in den D (Fig. 8).

On Kongsøya, the majority of the dens were facing southwards, between west and southeast. Altitudes varied between 30 and 250 metres above sea level and the angle of the entrance varied between 20 and 65 degrees. The majority of the dens were located less than one kilometre from the coast. Most of the dens were abandoned shortly after they had been opened, and the female bear and her cubs left it. Only in three cases the families stayed in their dens for 12, 17, and 17 days, probably because of bad weather conditions shortly after the dens had been opened for the first time.

13 single bears were observed on Kongsøya, in addition to five females each

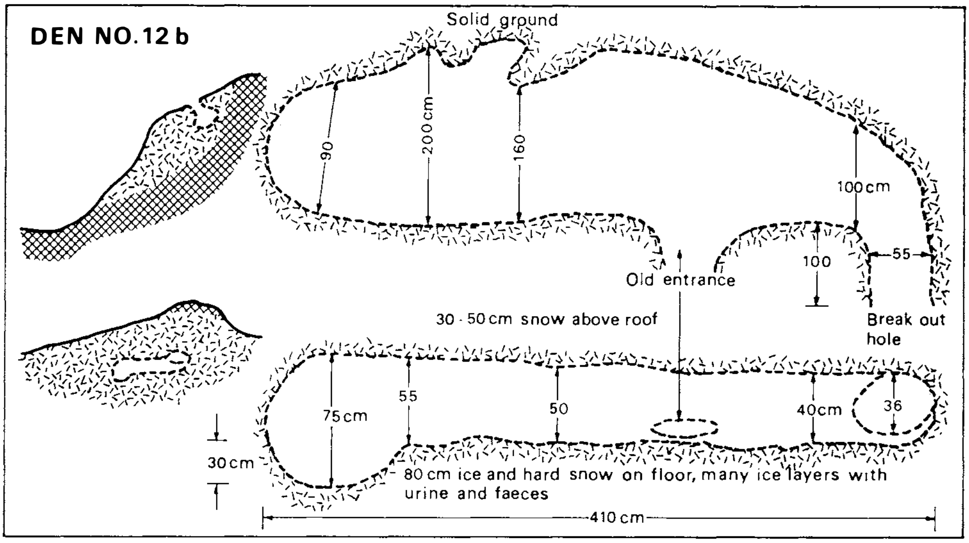


Fig. 7. *Cross section through polar bear den No. 12b on Kongsøya, March–April 1973.*
Поперечный разрез через берлогу белого медведя № 12b на о-ве Kongsøya в марте-апреле 1973 г.

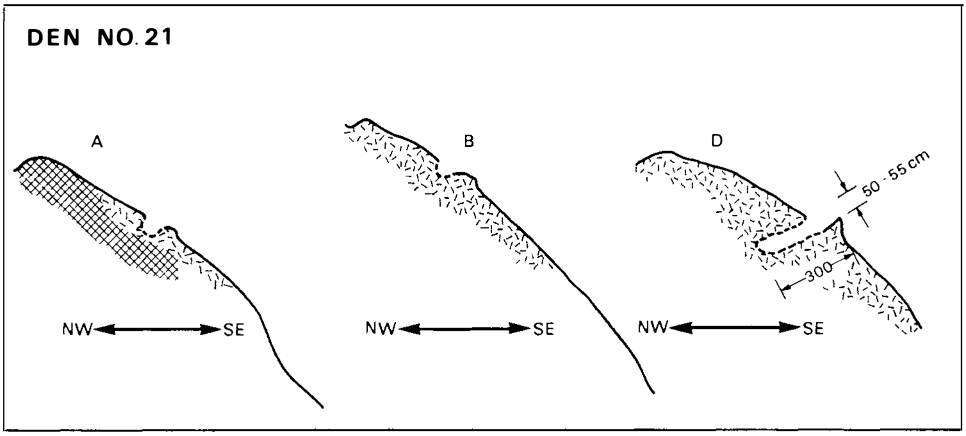


Fig. 8. *Cross section through polar bear den No. 21 on Kongsøya, March–April 1973.*
Поперечный разрез через берлогу белого медведя № 21 на о-ве Kongsøya в марте-апреле 1973 г.

with one cub, three females each with two cubs, and two females each with one yearling.

On Svenskøya, 23 days were effective for observations, during which 16 dens were found. Ten dens were found between 18 March and 26 March. Two dens were assumed to have been maternity dens, six to have been temporary dens, while in eight cases, the den type could not be determined (Fig. 2). Eight dens were dug out and described. The changes which had taken place in some of the Kongsøya dens were also observed in some on Svenskøya. The majority of the dens were facing southwest on the lee side of Kjølen. Altitudes varied between

50 and 150 metres and the angle of the entrance varied between 20 and 40 degrees. 19 single bears were observed on Svenskøya, in addition to two females each with one yearling.

Discussion

The polar bear den surveys in Svalbard in 1972 and 1973 show that Nordaustlandet and Kong Karls Land must be considered as particularly important denning areas. On Kong Karls Land there were 0.3 and 0.4 dens per square kilometre in 1972 and 1973, respectively. On Kongsøya alone, there were 1.5 dens per square kilometre of habitat suitable for denning in 1973. The fact that polar bear dens are far more numerous in the eastern and northern parts of Svalbard than elsewhere, may be explained by the marked differences in climate, temperature and ice conditions. C. VIBE (pers. comm.) claims that low winter temperatures are essential for the choice of den sites. There are also noticeable differences in topography between the areas preferred as den sites and other regions. It seems as if denning polar bears prefer low mountains, open valleys and a rolling landscape. I. SILIS (pers. comm.) has made polar bear den surveys on Kong Karls Land as well as on Twin Islands in the Hudson Bay area in Canada, and has noticed the similarities in topography between those two archipelagos. According to PAROVŠČIKOV (1964), Frantz Josef Land which is a good polar bear denning area, also has low mountains and open valleys like eastern and northern Svalbard. Photographs and descriptions of Wrangel Island (USPENSKIJ and KIŠČINSKIJ 1972), where polar bear dens are particularly common, show many similarities with polar bear denning areas in Svalbard too.

The locations of den sites in Svalbard in 1972 and 1973 seemed to coincide with the amount of snow which had accumulated in various areas throughout the year. Most dens were found in slopes where they were protected from prevailing winds from the north and northeast, and den entrances were normally facing away from the wind (Fig. 9). Polar bear dens in the Hudson Bay area are sometimes dug out in the earth as well as in the snow (JONKEL et al. 1972). In Svalbard earth dens were not found, although there were sometimes only a few centimetres between the den wall and the ground. This coincides with observations from other parts of the high Arctic (HARINGTON 1968, USPENSKIJ and KIŠČINSKIJ 1972).

Only ten den sites occupied on Kong Karls Land in 1972 were used again in 1973. Even in these cases, the site may have been moved a hundred metres or more, which however, could not be controlled. USPENSKIJ and KIŠČINSKIJ (1972) state that in the Soviet Arctic the same den sites are not necessarily used again every year in Wrangel Island. It is reasonable to assume that wind and snow may alter denning conditions in an area from one year to another, thus affecting the bear's choice of den site.

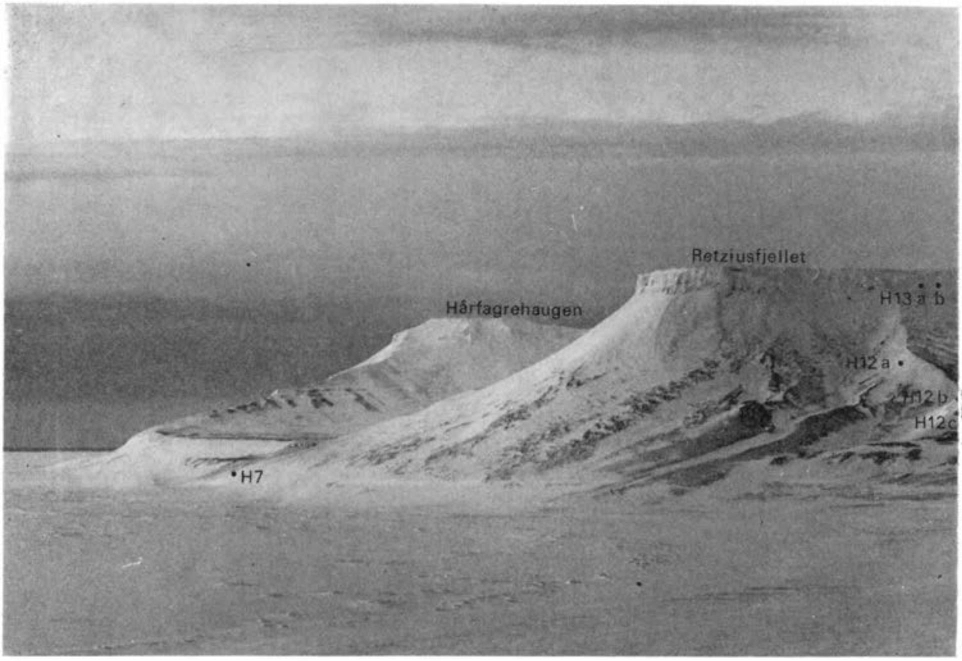


Fig. 9. *View towards Retziusfjellet and Hårfagrehaugen, Kongsøya. Dens found in the spring of 1973 are marked on the picture.*
Вид на горы Retziusfjellet и Hårfagrehaugen на о-ве Kongsøya. Берлоги, обнаруженные весной 1973 г., обозначены на снимке.

In Wrangel Island and in the Canadian high Arctic most dens are found within 8 kilometres from the coast, but some are located as much as 25 kilometres inland (HARINGTON 1968, USPENSKIJ and KIŠČINSKIJ 1972). In the Hudson Bay area, two major denning areas are located 20 and 70 kilometres inland (JONKEL et al. 1972). Most of the dens in Svalbard have been found less than one kilometre inland. This is partly due to the small sizes of islands and peninsulas suitable for denning.

HARINGTON (1968) and LØNØ (1972) state that polar bears depend upon the drift ice to go ashore and den. According to VIBE (1967), drift ice is the major factor determining where and when polar bears will appear along the east Greenland coast. LENTFER (1972) states that unfavourable ice conditions may sometimes prevent female bears from coming ashore, forcing them to den on the sea ice. In Wrangel Island, female polar bears will come ashore to den from mid September onwards, and in years with normal ice conditions, the majority will den up during October (USPENSKIJ and CERNJAVSKIJ 1965). According to PAROVŠČIKOV (1964), female polar bears on Franz Josef Land will den up during October and November. In 1971, northern Svalbard and Kong Karls Land were embraced by the ice by early October. The ice edge probably reached Barentsøya and Edgeøya by the end of October (VINJE 1973 and T. VINJE, pers. comm.). Comparing with information from other parts of the Arctic, the ice conditions should therefore not have prevented the female polar bears

Fig. 10. *Interior of polar bear den from Svenskøya. Note claw marks on ceiling and walls.*
Вид внутренности берлоги белого медведя на о-в *Svenskøya.* Заметно, как исчерчены коггями свод и стены.

from going ashore to dig their dens in any of those areas. In 1968, the ice surrounded Edgeøya and Barentsøya even earlier (LARSEN 1971). But very few signs of denning were found on those two islands in 1969 and 1972, in spite of partly intensive surveys both springs. It is unlikely, therefore, that the ice conditions account for the lack of dens on Barentsøya and Edgeøya. In 1972, the edge of the loose ice (i.e. about 3/10 ice cover) was found at Kvitøya, 200 kilometres north of Kong Karls Land, by late October. By 4 November, the loose ice had reached Kong Karls Land, while the more consolidated ice did not reach the islands before mid November (VINJE 1974 and T. VINJE, pers. comm.). Polar bear dens were as abundant on Kong Karls Land in 1973 as they had been in 1972. If we assume that the drift ice determines when the polar bears may come ashore, they cannot have reached Kong Karls Land before the first week of November in 1972, at the best.

In the Canadian high Arctic, most polar bear females with cubs leave their dens during late March and early April (HARINGTON 1968). In Franz Josef Land, the maternity dens are abandoned between the middle of March and the first week of April (PAROVŠČIKOV 1964), and in Wrangel Island, the mass emergencies occur between late March and the first week of April (USPENSKIJ and KIŠČINSKIJ 1972). On more southern latitudes, as in the Hudson Bay area, the majority of dens are abandoned during late February (JONKEL et al. 1972). LØNØ (1970) states that most polar bear family groups leave their dens in Svalbard between 10 and 25 April. But the observations from Nordaustlandet and Kong Karls Land in 1972 indicate that most of the dens had been opened and abandoned before mid April (LARSEN 1973). In 1973, most of the dens on Kong Karls Land had been abandoned before 1 April, although some females with cubs stayed in their dens long after that date. The fact that our data disagree with those of LØNØ may be explained by the fact that most of his information was based upon observations of family groups already out and having abandoned their dens some time before the records were made.

The den surveys on Kong Karls Land in 1973 were quite extensive, and probably few dens were overlooked by the field parties. Almost four-fifths of the dens found and controlled on Kongsøya were maternity dens. But probably only one-fourth of the controlled dens on Svenskøya were maternity dens. The relationship between maternity and temporary dens on the two islands is in agreement with the composition of the bear population observed on the islands at the same time. The data from Kong Karls Land in 1972 and 1973 indicate that about 40 maternity dens can be found there in a normal year.

Acknowledgements

I wish to thank JENS ANGARD, JAN BAKKERUD, SVEIN INGVALDSEN and CLAUS SANDE for their great interest and efforts while carrying out polar bear den surveys and investigations on Kong Karls Land in 1973. The project was made possbile by funds from Miljøverndepartementet, Roald Amundsens Minnefond, and World Wildlife Fund in Norway.

References

HARINGTON, C. R., 1968: Denning habits of the polaı bear. *Canadian Wildlife Service Report Series* **5**. 30 pp.

JONKEL, C. J., G. B. KOLENOSKY, R. J. ROBERTSON, and R. H. RUSSELL, 1972: Further notes on polar bear denning habits. *IUCN Publication New Series* **23**. 142–164.

LARSEN, T., 1971: Polar bear investigations in Svalbard 1968 to 1969. A progress report II. *Norsk Polarinstitutt Årbok* 1969. 94–100.

— 1972: Air and ship census of polar bears in Svalbard. *J.Wildl.Mgmt.* **36**(2). 562–570.

LENTFER, J. W., 1972: Polar bear — sea ice relationships. *IUCN Publication New Series* **23**. 155–171.

LØNØ, O., 1970: The polar bear in the Svalbard area. *Norsk Polarinstitutt Skrifter* Nr.149. 103 pp.

PAROVŠČIKOV, V. JA., 1964: A study of the population ot the polar bear in Franz Josef Land. *Acta soc. zool. Bohemoslov* **XXVIII** (2). 167–177.

USPENSKIJ, S. M. and F. B. CERNJAVSKIJ, 1965: Material on the ecology, distribution and protection of the polar bear in the Soviet Arctic. In: *Game animals. Biology and economic exploitation. Rossel'khozizdat*, Moscow. 215–228.

USPENSKIJ, S. M. and A. A. KIŠČINSKIJ, 1972: New data on the winter ecology of the polar bear in Wrangel Island. *IUCN Publication New Series* **23**, 181–197.

VIBE, C., 1967: Arctic animals in relation to climatic fluctuations. *Medd. om Grønland* **170**(5), 227 pp.

VINJE, T., 1973: Sea ice and drift speed observations in 1971. *Norsk Polarinstitutt Årbok* 1971. 81–85.

— 1974: Sea ice and drift speed observations in 1972. *Norsk Polarinstitutt Årbok* 1972. 140–145.

Studies of the Svalbard reindeer

By Olav Hjeljord[1]

Contents

Abstract

During summer the Svalbard reindeer (*Rangifer tarandus platyrhynchus*) are mainly grazers, feeding in interior valleys and on coastal plains. Their late winter range in the eastern and central part of the archipelago is on the high mountain plateaus, where they feed on woody plants, herbs and mosses. In the northern and northeastern areas, lichens growing on rocks and vegetation on rookery-fertilized slopes play an important role.

Shed antlers are significantly larger in central Spitsbergen than on Edgeøya. Possible reasons for this are discussed.

Calf percentage in Svalbard is usually around 20. This figure appears to be fairly constant throughout the archipelago in spite of differences in habitat saturation.

Introduction

When Dutch whalers arrived in Svalbard in the 15th century, they found large numbers of reindeer on the islands. Towards the end of the 19th century and in the beginning of the twentieth the animals were heavily hunted and nearly exterminated from large parts of their original range, particularly in the easily accessible western part of the archipelago (Lønø, 1959). When the islands came under Norwegian jurisdiction in 1925, the reindeer were protected and have since gradually increased. Today reindeer occur in more or less isolated subpopulations throughout greater parts of their original range.

[1] Norges Landbrukshøgskole, 1432 Ås-NLH.

The Svalbard reindeer differ from reindeer elsewhere in several aspects, primarily in the lack of herd instinct and in their small size. Svalbard imposes a more severe environment than most other reindeer habitats. This is reflected in the sparse vegetation. The various species of lichen commonly regarded as important reindeer forage are scarce or lacking in Svalbard.

Except for stray dogs there are no predators capable of killing reindeer in Svalbard, and parasites such as warble- and nostril flies do not occur on the islands.

Few studies have been carried out on the Svalbard reindeer. In particular there is scant information on feeding habits, range and seasonal migration patterns. The main objective of this study has been to collect data on these aspects of the animals' ecology.

The field work was performed in the course of activities directed by the Norwegian Ministry of Environment. As emphasis was on the general conservation work, the reindeer data were collected when time and place permitted. The material presented herein is therefore unfortunately somewhat heterogenous.

Methods

Most of the field work was done on Edgeøya. A thorough air survey of the reindeer population on the island (25 flight hours) was conducted in late April 1972 using a Cessna 182 with two observers. During one week in early May 1972, reindeer were studied on Depotodden, Nordaustlandet. In August 1973 the reindeer on northern Edgeøya were counted from helicopter. General field work included sampling of vegetation types and grazing intensity on feeding sites. Vegetation types were determined by plot sampling with a rectangular frame 20 × 40 cm. Range use was quantified by counting number of grazing marks on each plant species. Food habits were also determined on the basis of botanical composition of rumen contents from eight animals shot on the winter range. The analysis was done by point sampling (GAARE, 1968) at the Norwegian Game Research Institute.

Herd productivity was estimated by counting calves in July/August.

To investigate size differences between reindeer in Spitsbergen and on Edgeøya, 50 of the largest shed antlers found on comparable habitats on the two islands were measured. The size of the antlers was determined by measuring the greatest length along the beam from burr to brow tine and circumference above the burr.

Results

HABITAT PREFERENCE

As seen in Fig. 1 the reindeer on Edgeøya utilize two distinctly different habitats during the year. While they in summer forage on coastal plains and inland valleys, with the advancement of winter they ascend to the high mountain

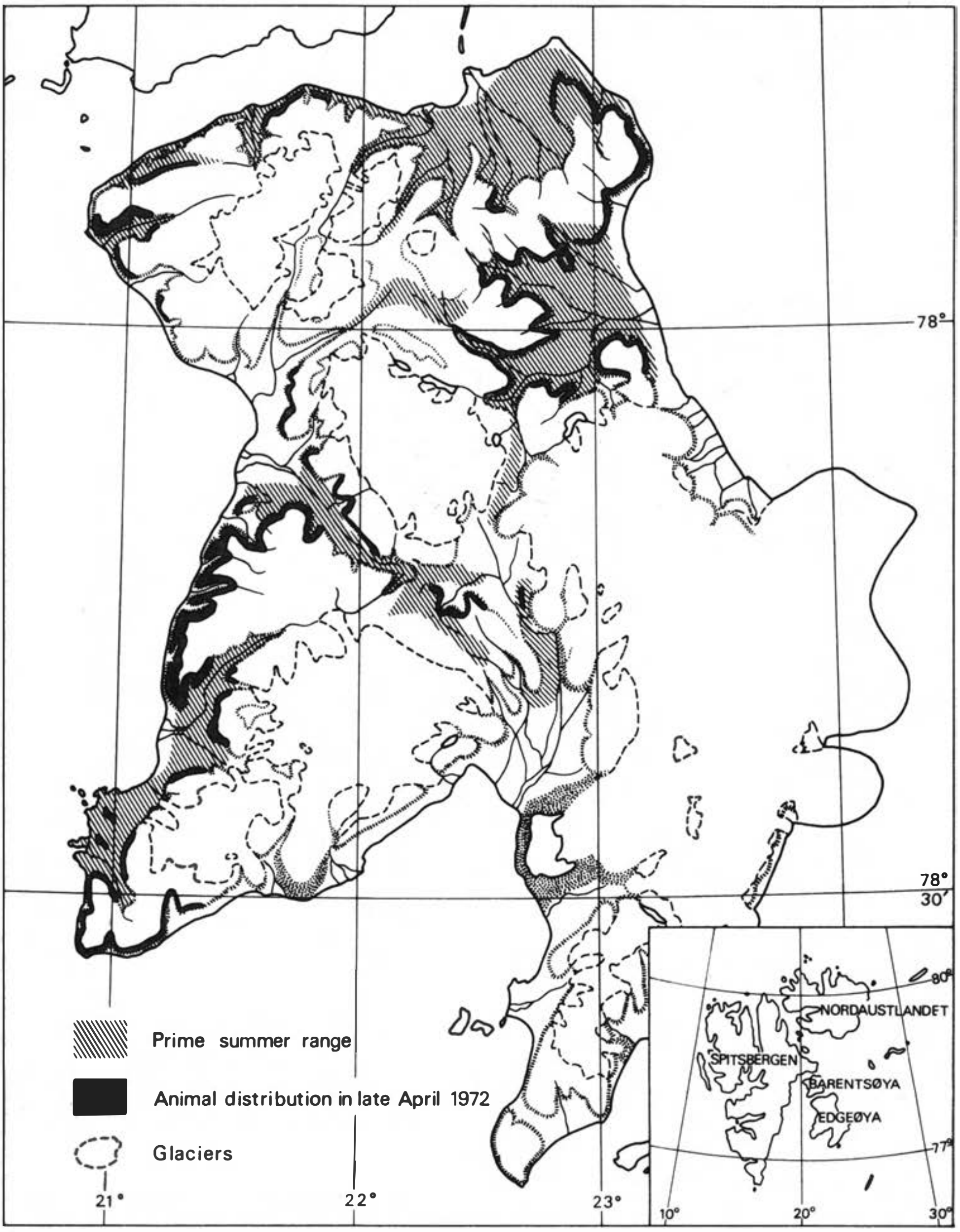


Fig. 1. *Range utilization by reindeer on Edgeøya. Scale 1:750 000.*

plateaus (400–500 m above sea level). Here they feed on the edges of the plateaus blown free of snow (Fig. 2). The migration to the high mountains is apparently a consequence of snow covering the lower regions. The commencement of the upward migration might therefore differ from year to year. In the winter of 1971/72 the animals were still commonly seen in the valleys on Edgeøya in February, but disappeared gradually throughout March (HÅVALSRUD, personal

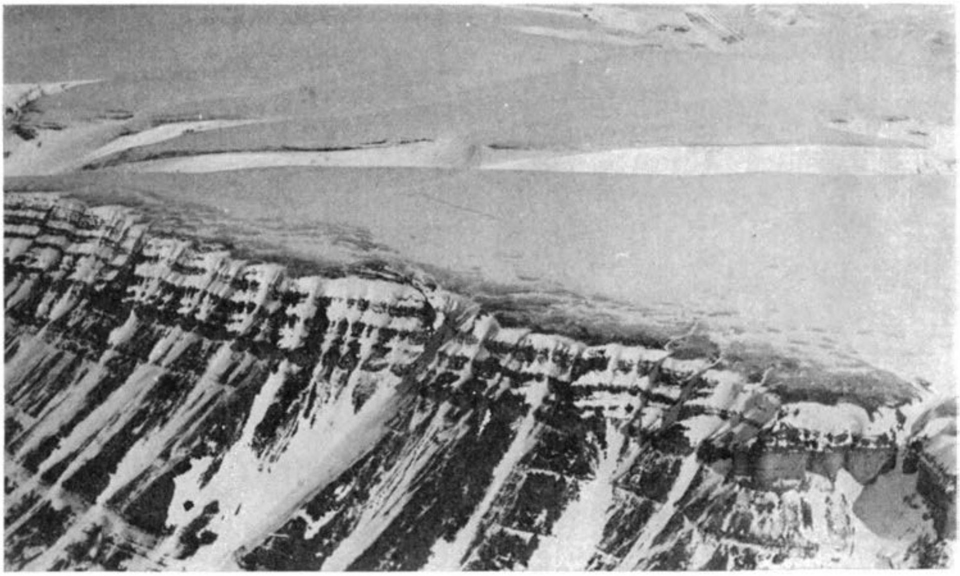


Fig. 2. *Edge of plateau mountains blown free of snow. Reindeer habitat, Edgeøya late April 1972.*

communication). On the air survey in late April, approximately 90% were found on the plateaus.

The mountain plateaus on Edgeøya consist of flat lying sediments. These are also found in central Spitsbergen, particularly on Nordenskiöld/Sabineland between Isfjorden and Van Mijenfjorden. The geomorphology of this area, therefore, resembles that of Edgeøya, and the reindeer here appear to have a seasonal migration pattern similar to that on Edgeøya.

In North Spitsbergen and on Nordaustlandet the base rock consists of eruptives. This influences both general topography and vegetation. In northern Spitsbergen the mountains are rather precipitous, and the typical plateau mountains are absent. The reindeer here are in winter frequently seen climbing talus slopes and slopes below bird rookeries (J. ANGARD, personal communication). The significance of this will be discussed under forage preference.

Nordaustlandet presents a rolling flat topography with few high mountains. Due to the severe climate and poor soil the conditions for plant growth are marginal. Abundant vegetation is restricted to slopes fertilized by bird rookeries. No data have been collected on the summer habitat in this area. During the survey flight in April 1972, scattered animals were observed around bird rookeries and on talus slopes.

FORAGE PREFERENCE

A. *Edgeøya*

The figures for plant coverage in Table 1 indicate the average composition of typical tundra vegetation in Plurdalen, Edgeøya. The analysis represents the drier part of each frost polygon. The more humid cracks between the polygons

Table 1.

Vegetation composition of feeding sites on moss tundra in Plurdalen, Edgeøya, with indication of grazing intensity on different plant species.

Species	Coverage*)	Utilization**)
Bryophyta	5–4	—
Salix polaris	3–2	5
Polygonum viviparum	1	17
Alopecurus alpinus	1	250
Poa sp.	1	83
Draba sp.	1	—
Saxifraga oppositifolia	1	—
S. caespitosa	1	—
Pedicularis hirsuta	1	6
Luzula confusa	1	36
L. arctica	+	6
Papaver dahlianum	+	—
Ranunculus sp.	+	4
Saxifraga sp.	+	—
Carex sp.	+	—
Festuca sp.	+	—
Lichens	+	—
Peltigera sp.	+	5
Fungi	+	15

*) Braun-Blanquet's system, average values based on 100 samples, the table includes only the most common species.
**) Number of grazing marks on each species.

generally have a higher amount of grasses such as *Alopecurus alpinus* and *Dupontia fisheri*. There are a number of other vegetation types in the valley, but a detailed vegetation study is outside the scope of this investigation. The type described in Table 1 represents the typical moss tundra on Svalbard, covering larger parts of the vegetated interior valleys. It is also the one most commonly utilized by the reindeer during the summer. In the lower part of the valleys and on the coastal plains the humidity increases, resulting in numerous shallow ponds with relatively dense growth of grasses and sedges.

The figures showing forage utilization in Table 1 should be regarded as only approximate, due to constant and random errors varying with plant form and abundance. In particular feeding signs on *Salix polaris* and on *Polygonum viviparum* and other forbs are difficult to detect, and are thus probably underestimated in the analysis relative to grass-like plants. The total amount of grasses and sedges eaten is, however, greater than what would be found on the dry moss tundra in Table 1. This reflects the fact that the animals spend considerable time feeding on grass- and sedge patches in the cracks between frost polygons and in shallow ponds. In general, therefore, it seems likely that grasses form a major component of the animals' summer diet.

Table 2 shows forage utilization by four reindeer shot on a high winter range

Table 2.

Rumen content of four reindeer collected on high mountain range on Edgeøya in April 1972. Right column indicates plant coverage on the feeding sites.

Species	Samples 1	2	3	4	Average	Coverage on feeding site
Grass-like (Monocotyledoneae)	16[a]	21	46	26	27	1[b]
Luzula sp.	1	10		6	5	1
Carex sp.	10	11	16		9	+
Festuca sp.		tr[c]	5		1	+
Poa sp.			10	6	4	+
Deschampsia sp.	2	tr	4	10	4	+
Gramineae	3		11	4	4	+
Forbs	6	4	6	21	9	1
Cerastium arcticum				12	3	+
Draba sp.	3	4	3	6	4	1
Polygonum viviparum	2		1	2	1	+
Saxifraga caespitosa						+
Saxifraga sp.	1		2	1	1	+
Papaver dahlianum						+
Silene acaulis						+
Woody plants	24	23	42	31	30	2
Salix polaris	9	16	32	19	19	1
Saxifraga oppositifolia	15	7	10	12	11	1
Lichens	1		1	3	1	+
Cladonia sp.	tr		1		tr	
Ochrolecia sp.	1				tr	
Stereocaulon sp.				1	tr	
Parmelia sp.				2	tr	
Mosses (Bryophyta)	53	51	6	17	32	4–2
Bryum sp.	10	10			5	
Dicranum sp.	12	11		6	7	
Polytrichum sp.	11	10	3	7	8	
Rhacomitrium sp.	10	10	3		6	
Drepanocladus sp.				4	1	
Moss not identified	10	10			5	

[a] Units in percent
[b] Braun Blanquet's system
[c] Traces <1 percent

on Edgeøya. The Table also indicates the vegetation composition of their feeding site. The reindeer on this winter range ate mainly mossess (32 percent), woody perennial plants (30 percent), and grass-like plants (27 percent). Forbs are of lesser importance (9 percent) and lichens are negligible (1 percent).

B. *Nordaustlandet*

As seen from Table 3 the rumen contents of the animals shot on Nordaustlandet differ from those from Edgeøya in containing more forbs (16 percent) and in particular by the high content of lichens (19 percent). The lichens are mainly crustaceous members of the genus *Parmelia* growing on rocks. These lichens stick hard to the rock surface and are even difficult to scrape off with a fingernail. A study of feeding time indicated the attractiveness of these lichens, for although snow-free patches with dry grasses and herbs were abundant, the animals spent approximately 70 percent of a 4 hour period feeding on lichens on rocks. The animals would also climb the cliffs and talus slopes to "gnaw on rocks".

On their winter range the Svalbard reindeer appear to graze on exposed vegetation. Only occasionally are they seen pawing with their forefeet to expose additional food from under the snow.

Table 3.

Rumen content of four reindeer collected on Nordaustlandet in early May 1972.

Species	Samples 1	2	3	4	Average
Grass-like (Monocotyledoneae)	11[a]	39	10	10	16
Carex sp.		12			3
Festuca sp.		2			tr
Poa sp.		10	6	8	6
Deschampsia sp.		4	4	2	2
Gramineae	11	11			5
Forbs	18	3	32	9	16
Cerastium arcticum			15	4	5
Draba sp.			15	4	5
Polygonum viviparum		tr[b]			tr
Saxifraga caespitosa	15				4
Saxifraga sp.	2	3	2	1	2
Potentilla sp.	1				tr
Woody plants	1	20	8	2	8
Salix polaris		6			2
Saxifraga oppositifolia	1	14	8	2	6
Lichens	26	4	22	26	19
Cladonia sp.	3				1
Parmelia sp.	23	4	22	26	18
Mosses (Bryophyta)	43	32	26	52	39
Bryum sp.	11	7	7	10	9
Dicranum sp.		2	1		1
Polytrichum sp.	5	15	6	6	8
Rhacomitrium sp.	15	8	8	22	13
Moss not identified	12		4	14	8

[a] Units in percent

[b] Traces <1 percent

Population dynamics

On the air survey on Edgeøya in April 1972 a total of 1568 animals were counted. This compares well with the figure of 1448 animals counted in August 1969 by NORDERHAUG (1971). Surveys of the south-western part of Edgeøya in the summer of 1971 and of the northern part of Edgeøya in the summer of 1972, also gave population figures similar to those observed by NORDERHAUG in 1969.

On Edgeøya in July 1971 calves were found to make up 20 percent of 513 animals counted. When estimates of herd productivity are made during summer, special care must be taken to obtain a representative sample, as the sexes to a large extent are segregated. There appears to be a preponderance of old males on the coastal plains, while the cows with calves and the yearlings retreat to the interior valleys. This segregation is illustrated by the regional figures for herd composition on Edgeøya in early July 1971. On the tundra adjacent to Diskobukta 9 percent of the 127 animals were calves, while corresponding figures for upper Plurdalen were 27 percent of a total of 280 observed animals.

The next year (July 1972) the calf percentage on Edgeøya was comparatively low: 17 percent in Plurdalen and 8 percent in Guldalen. On the other hand the number of calves in Spitsbergen did not appear to be particularly low that year; in Reindalen in July 22 percent of the deer were found to be calves. In 1973 productivity was up again on Edgeøya; in July 21 percent of the reindeer in Rosenbergdalen were calves.

Although it has never been verified by actual measurements the reindeer on Edgeøya and Nordaustlandet are generally regarded as being smaller than those in central Spitsbergen. In order to get an indication of any size difference between reindeer on Edgeøya and in Spitsbergen, the sizes of shed antlers found on the two islands were compared (Table 4). The mean lengths of antler beams from central Spitsbergen (Reindalen) and from Edgeøya (Plurdalen) were 100 cm and 89 cm respectively. The difference was highly significant ($P<0.01$). The largest antler was found in Spitsbergen and measured 115 cm. The mean circumference above the burr was 15.2 cm in Spitsbergen and 14.7 cm on Edgeøya. This difference was significant on the $P<0.1$ level.

Table 4.

Comparison between largest shed reindeer antlers from Edgeøya and Spitsbergen.*

Measurement taken	cm*	Range cm
Length of beam		
Spitsbergen	100	85–115
Edgeøya	89	80–109
Circumference above burr		
Spitsbergen	15.2	12.0–17.7
Edgeøya	14.7	11.2–17.1

* Comprise fifty of the largest antler beams collected within comparable habitats on each island.

Discussion

The reindeer on Nordaustlandet seem to prefer lichens over vascular plants on their winter range. The reindeer on Edgeøya, however, do not appear to eat significant amounts of lichens.

This difference in feeding habits may be due to the scarcity of lichens on the sedimentary rocks on Edgeøya. These rocks are rather loose compared to the eruptives on Nordaustlandet. They erode quickly and form a rather poor growth substrate for lichens. For the same reason large boulders are uncommon on Edgeøya but frequent on Nordaustlandet. On Nordaustlandet these large boulders extend above the snow surface and supply easily accessible lichens throughout the winter. In Norway reindeer have also been observed feeding on crustaceous lichens on rocks (SKJENNEBERG et al., 1971). The small amount of woody plants in the rumen samples from Nordaustlandet reflects that the animals were shot on rookery-fertilized slopes dominated by grasses and forbs.

There is a high amount of mosses in the rumen samples from both areas (Tables 2 and 3). Mosses are generally thought to be low among the reindeer's forage preferences. When found in rumen analyses they are usually believed to be ingested accidentally (KELSALL 1968, SKJENNEBERG et al., 1971). On Edgeøya and Nordaustlandet, however, the mosses comprise more than 50 percent in the rumen samples of some animals, and they have undoubtedly been grazed actively. The rumen of the Svalbard reindeer appears to be relatively large (40–50 percent of dressed weight). It is of interest in this connection that the fermenting chamber (caecum) in small rodents is most highly developed in those species which feed on mosses (LANGE and STAALAND 1970). Further research is needed on this subject.

The higher vegetation is generally more abundant in central Spitsbergen than in the eastern and northern parts of the archipelago (RØNNING, 1964). This is caused by the system of ocean currents creating a harsher climate in the eastern and northern regions. This would imply better range quality in central Spitsbergen than on Edgeøya to the east, and the recorded difference in antler size may partly be related to this factor. The higher saturation of habitats on Edgeøya (to be discussed) which implies greater competition for forage might also be a factor contributing to smaller antler size. Work on white-tailed deer *Odocoileus virginianus* (COWAN and LONG n.d.) has demonstrated a direct relationship between nutrition and antler development for that species. And from reindeer husbandry in Norway it is known that antler size decreases with decreasing pasture quality (SKJENNEBERG and SLAGSVOLD, 1968). Body size is also governed by quantity and quality of forage, but this parameter was not measured in the present investigation.

The density of reindeer appears to be greatest in central Spitsbergen. Recent surveys indicate that earlier estimates of animal numbers on Nordenskiöld/Sabineland have been too low. GOSSOW and THORBJØRNSEN (1974) counted 2972 animals in this area in 1972. Applying this figure to NORDERHAUG's estimates of total reindeer range (NORDERHAUG, 1969) gives approximately 3 animal/km² on Nordenskiöld/Sabineland. The density on Edgeøya has been estimated at approximately 1 animal/km² (NORDERHAUG, 1971). The better ranges in central Spitsbergen, therefore, apparently support both larger animals and denser populations than on Edgeøya.

When comparing reindeer densities in different parts of the Svalbard archipelago, trends in the population development must be considered. The reindeer on Edgeøya are probably at the limit of the carrying capacity of the range. The counts carried out on Edgeøya in 1972 and 1973 show no clear trend of increase compared to NORDERHAUG's counts from 1969. The difference of 120 animals (8 percent of total) between the counts from *1969 and 1972* is within expected limits of variability for aerial surveys of this type. In Spitsbergen, on the other hand, the population appears to still be increasing (GOSSOW and THORBJØRNSEN, 1974). This seems logical considering that the animals in Spitsbergen were more severely hunted than those of the less accessible Edgeøya (LØNØ, 1959).

As there are no predators on Svalbard, the question arises as to which factors limit population size. This investigation provides few answers to this question. The calf percentage appears to be fairly stable throughout the archipelago. The average percentage of approximately 20 found in this study compares well with figures from other investigations. Summer counts on Edgeøya in 1969 (NORDERHAUG, 1971) and in 1969 (OOSTERVELD, 1973), on Barentsøya in 1969 (NORDERHAUG, 1971) and in central Spitsbergen in 1972 (GOSSOW and THORBJØRNSEN, 1974) gave calf percentages of 20, 18, 17.8 and 20.1, respectively. Although numbers of calves were low on parts of Edgeøya in 1971, there is no indication of different natality rates between the various subpopulations of the archipelago. One might have expected a higher natality rate in the expanding Spitsbergen population relative to the stable Edgeøya population. A larger material might, however, show such differences. If, on the other hand, natality remains unaltered or is only slightly altered with an increase in population density, stabilization in animal numbers will have to be achieved through an increase in the rate of mortality.

One would expect the high concentration of animals on the late winter ranges to be very destructive to the sparse vegetation on these exposed sites. But there have been no reports of large dieoffs of animals on the islands as would have been expected if the grazing areas had been periodically over-used. Apparently the Svalbard reindeer is well adapted to this high Arctic environment.

References

COWAN, R. L. and T. A. LONG, n.d.: Studies on antler growth and nutrition of white-tailed deer. *Penn. Coop. Wildl. Res. Unit Paper* No. 7.

GAARE, E., 1968: Prøver av vominnhold i studiet av villreinens konsumpsjon i vinterhalvåret. *Viltstell og viltforskning i Norge. Statens Viltundersøkelser.* (Mimeographed). 23–25.

GOSSOW, H. and S. R. THORBJØRNSEN, 1974: Air and ground survey of reindeer in Nordenskiöld Land and Sabine Land, Spitsbergen. *Norsk Polarinstitutt Årbok* 1972. 83–88.

KELSALL, J. P., 1968: The Caribou. *Canad. Wildl. Serv.* Monograph 3. Ottava. p. 76.

LANGE, R. and H. STAALAND, 1970: Adaptions of the Caecum-Colon Structure of Rodents. *Comp. Biochem. Physiol.* **35**. 905–919.

LØNØ, O., 1959: Reinen på Svalbard. *Norsk Polarinstitutt Medd.* Nr. 83. 31 pp. (Særtrykk av *Fauna* **2**, 1959).

NORDERHAUG, M., 1969: Svalbard-reinen i 1960-årene. Beiteareal og bestand. *Fauna*, **22**. 253–264.

— 1971: Investigation of the Svalbard reindeer (*Rangifer tarandus platyrhynchus*) in Barentsøya and Edgeøya, summer 1969. *Norsk Polarinstitutt Årbok* 1969. 70–79.

OOSTERVELD, P., 1973: (Typoscript about preliminary results of a reindeer research project on Edgeøya in 1968–69). 14.

RØNNING, O. I., 1964: Svalbards flora. *Norsk Polarinst., Polarhåndbok nr. 1.* Universitetsforlaget.

SKJENNEBERG, S. og L. SLAGSVOLD, 1968: *Reindriften og dens naturgrunnlag.* Universitetsforlaget. 23–26.

SKJENNEBERG, S., P. FJELLHEIM, E. GAARE og D. LENVIK, 1971: Reinens beiteopptak. *Statens Reinforsøk, melding nr. 2.* 23–25.

On the biology of char (*Salmo alpinus* L.) in Svalbard

I. Migratory and non-migratory char in Revvatnet, Spitsbergen

By NILS GULLESTAD[1]

Contents

Abstract

Some biological parameters of migratory and non-migratory char in Revvatnet, Spitsbergen, have been studied during the summers (July and August) 1962, 1963, and 1964.

Migratory char: The first seaward migration takes place between the 4th and the 9th year (88.1% between the 5th and the 7th year). Two types of first seaward migration are indicated. One, an active smolt migration around the end of June—beginning of July. The other, a random, young char (12–17 cm) nutritional migration downstream during the summer season, generally reaching salt water sometime in August. Sexual maturity is reached between the 7th and the 11th year (93.3% between the 8th and the 10th year.) There are indications that a two year spawning cycle exists.

Non-migratory char: Sexual maturity occurs between the 6th and the 13th year (72.5% between the 8th and the 9th year). A spawning cycle of at least two years is usual.

Introduction

The char (*Salmo alpinus* L. = *Salvelinus alpinus* (L.)) is a migratory or non-migratory salmonid found in cold waters of the northern hemisphere. The migratory form spawns and lives its early life in freshwater, but later undertakes

[1] Nordland Regional College, 8001 Bodö, Norway.

yearly migrations to the sea during the summer period (NORDENG 1971). It has been recorded from Greenland, Iceland, Svalbard, Novaya Zemlya and the northern parts of Norway, Siberia, Canada, and Alaska (GRAINGER 1953). Non-migratory forms also exist in the same area. This char spends its whole life in fresh water, just like those found in the southern part of Norway, in Sweden, Finland, Great Britain, the Alps, and in the Soviet Union (NORDENG 1961).

The char, popularly known as the "Spitsbergen Salmon", is the only freshwater fish on Svalbard. Fantastic accounts exist of the enormous quantities of char to be found there, but only one scientific report is available (DAHL 1926).

The purpose of the present study was to obtain some information about age, growth, spawning frequency and migration of char in Svalbard.

Area description

Revvatnet lake lies in the southern part of Spitsbergen (Fig. 1). The climate of this area is arctic. The average monthly temperatures for 1947–1962 (Kapp Linné) show that only June, July, August and September have an average temperature of above 0°C, the highest average temperature, 4.5°C, being recorded in July (STEFFENSEN 1969). The average precipitation for the years 1946–1965 (Kapp Linné) was 378 mm fairly evenly distributed throughout the year (STEFFENSEN 1969).

Revvatnet is situated 30 m above sea level and has a maximum length and breadth of 2150 m and 600 m, respectively, and a surface area of 0.9 km^2 (Fig. 1). The lake consists of a larger and a smaller basin with maximum depths of 27 m and 10 m, respectively (KUZIEMSKI 1959). The bottom is covered with mud except for a small area at the southern end of the lake and directly beneath the steep western slope.

Revvatnet is a characteristically oligotrophic lake greatly influenced by supply of glacial melt water (KUZIEMSKI 1959). Measurements taken in 1962, 1963, and 1964 show that it has a continuous summer circulation and that the surface temperature rarely rises above 6.0°C. The pH generally varied between 6.6 and 7.0, and the total hardness between 10 and 12 mg $CaCO_3$/l, Ca-hardness between 9 and 10 mg $CaCO_3$/l, and conductivity between 40 and 45 μmho/cm (GULLESTAD in prep.).

The lake is usually ice-free from the end of July—beginning of August to the end of September, depending on the climate each summer season. In 1963 the ice disappeared on 2 August and in 1964 about 10 August.

Revelva is about 4.5 km long with a breadth varying between 8 m and 40 m. The average depth of the river is about 0.2 m, nowhere exceeding 1 m. The river is ice-free from the second half of June when the water rises.

The char is the only fish in the watercourse.

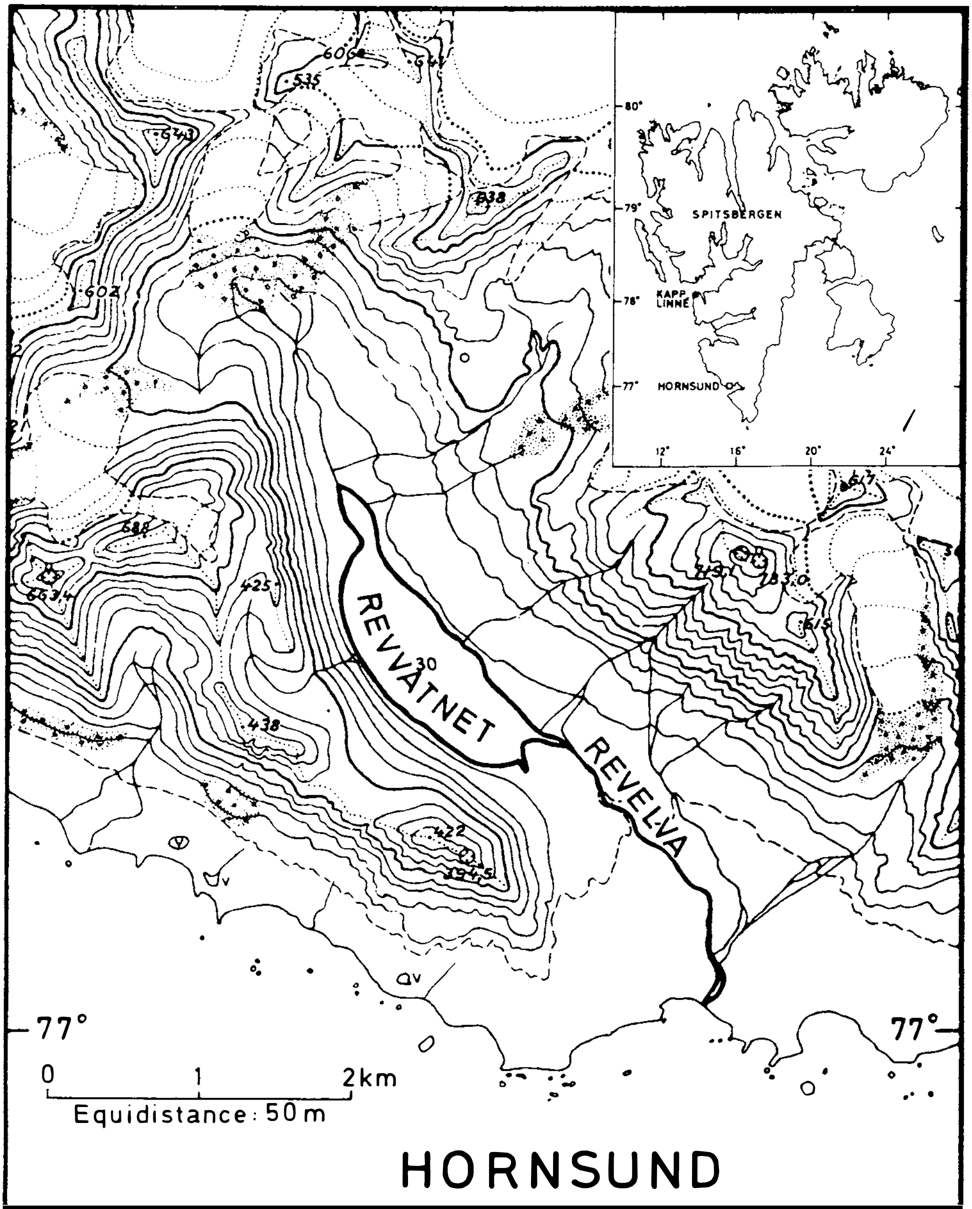


Fig. 1. *Lake Revvatnet and its surroundings.*

Material and methods

A survey of the char collected and the gear used in the field are given in Table 1.

Based on coloration, condition and scale analyses, the fish are classified in the following manner:

Table 1

Catch and fishing gear used in sampling

Year	Period	No. of char	Fishing gear and mesh size
1962	August	36	Net: 29, 35, 40 and 45 mm
1963	July—August	74	Net: 10, 18, 20, 26, 29, 35, 40 and 45 mm Hairnet: 5–7 mm, Trap 12 mm
1964	August	45	Net: 10, 18, 20, 26, 29, 35, 40 and 45 mm Hairnet: 5–7 mm
Total		155	

I. *Migratory char* (77 individuals) — Fish larger than 20 cm in well nourished condiction, shiny and with moderate spawning coloration. Scales showing clear characteristics of sea growth.

II. *Non-migratory char* (44 individuals) two groups —

A. Fish larger than approximately 20 cm usually in poorly nourished condition. Relatively dark upperside and strong spawning coloration, yellow and orange, caught only in the lake.

B. Mature fish, 14–20 cm long. Pale grey-yellow spawning coloration, caught only in the river.
The scales from groups A and B showed that neither had been in the sea. The two groups are treated together here, but there are indications that they belong to separate populations.

III. *Young char* (34 individuals) — Immature fish less than 20 cm long, caught in freshwater only. They form a very homogenous group and the division into migratory or non-migratory char is impossible at this point.

In 1963 Revelva was closed by a netting barrier about 25 m from the sea. Two fish traps were placed in the barrier, one for upgoing and one for downgoing fish (Fig. 2). Because of heavy flooding throughout July, the traps functioned only between 26 and 29 July, between 30 July and 1 August, and between 3 and 28 August, and were inspected twice a day.

In 1962 and in 1964 fishing was undertaken with nets in Revvatnet, at the mouth of Revelva, and in the sea outside, while in 1963 fishing only took place in the lake. To catch the smallest char, small hair nets were used (mesh size 5–7 mm). This proved effective in the shore zone of Revvatnet. After periods of flood several small pools were formed where a few char as small as 5 cm long were caught.

In the field the char were measured (total length), weighed and sexed, and scales and otoliths were conserved. The degree of maturity of the gonads was tabulated according to DAHL (1943). DAHL divided the gonads into seven main stages. Fish in stages I and II will not spawn, while fish in stages III–V shall

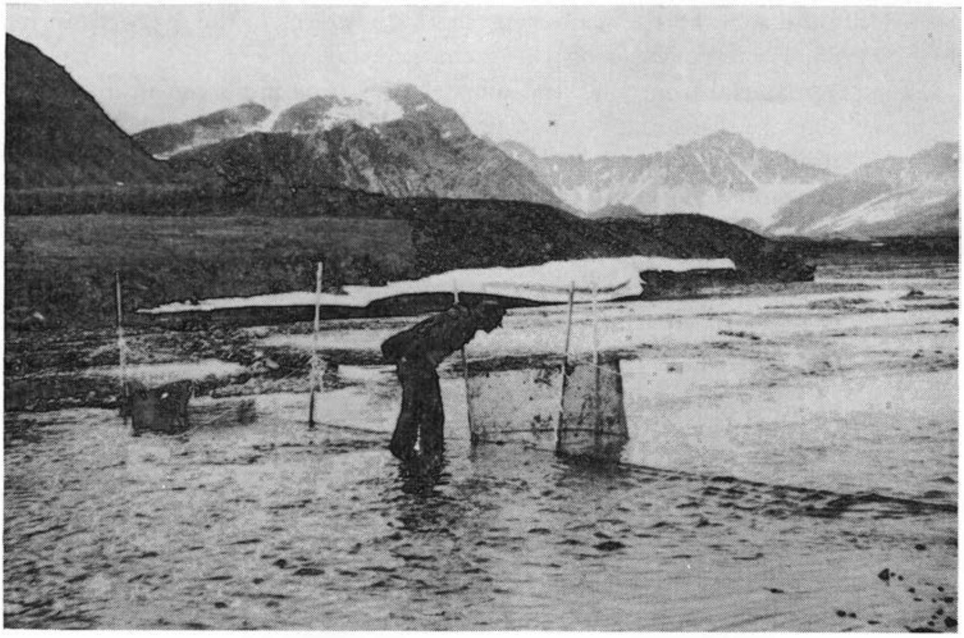


Fig. 2. *Lower part of Revelva (river) with barrier and two traps.*

spawn the same season. Fish in stages VI and VII are either spawning or have just spawned. In Revvatnet, however, it was impossible to determine whether or not char in stage III should spawn the same season.

Another problem coming up when DAHL's system is used, is a general tendency to underestimate the earliest stages of maturity in males. The problem may be due to the somewhat diffuse and subjective criteria. Fish tabulated at stages I, II, and III according to DAHL are, therefore, tabulated as stages II, III, and IV, respectively, in the present paper.

The otoliths have been graded for age according to the methods referred to in NORDENG (1961).

Age at first spawning was determined on the basis of otolith imprints (NORDENG 1961). In non-migratory char there were many cases where several consecutive zones could be interpreted as indicating first spawning. The innermost of these was always taken as an indication of sexual maturity age. It is not determined to what degree poor nutritional seasons may produce the same imprint in the otolith as spawning.

To determine age at first seaward migration both otoliths and scales were used from each fish. The transition from fresh- to saltwater was easy to see in the scales. By using age, read from the otoliths, the age at transition from fresh- to seawater can be read from the scales by counting the winter zones from the outer edge inwards. Only fish where no growth stagnation can be proved from the edge of the scales lend themselves to this method.

In calculating the lengths of the char at earlier ages LEA's (1910) formula was used. Only the zones in the scales representing sojourns in the sea were fit for use. In 1963, 47 char measuring 12–40 cm were tagged.

The char material from 1962 was for a shorter time preserved in formaldehyde (4%) before dissecting out and preparing the otoliths. As a consequence of this, certain otoliths are sagged at the edges and therefore not suitable for definite age estimation. In fish where this was the case the minimum age was calculated.

Results

The total catch of char (155 individuals) during the present investigation is given in Fig. 3.

MIGRATORY CHAR

Age and growth. — Only smolt (char at the stage of first seaward migration) and post-smolt are represented in Fig. 4. Char, at pre-smolt stage, included in the group "young char", are treated later under non-migratory char.

Age at first seaward migration. — Most scales (86.4%) had a sharp transition zone clearly marking the change from fresh- to seawater (Fig. 5a). In the rest of the material (13.6%) the transition zone was more diffuse (Fig. 5b). This zone was made up of 2 or 3 sclerites. The breadth of each sclerite and the distance between them are about half of those in seawater, but larger than those in

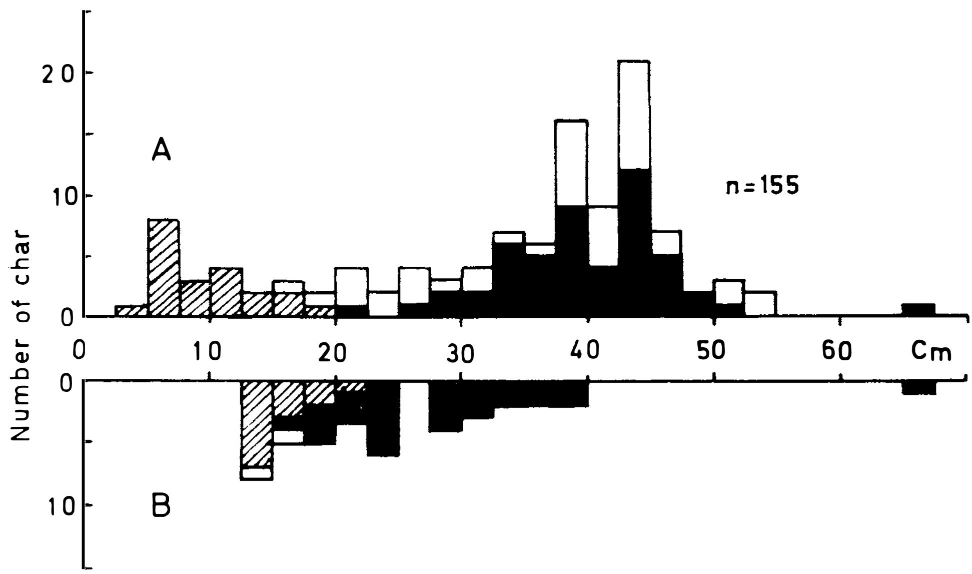


Fig. 3. *Total catch of char in nets, scoop and hair nets (A), and in traps (B). Shaded columns = young char, black columns = migratory char, and white columns = non-migratory char.*

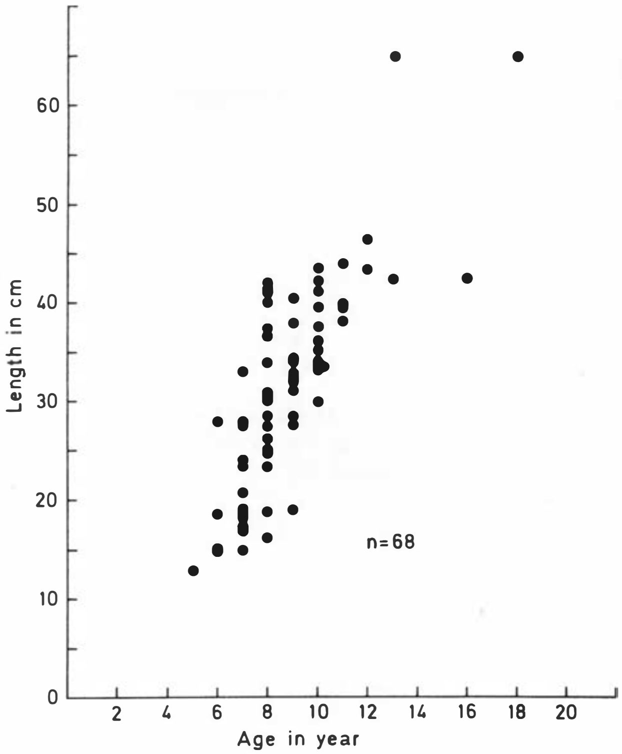


Fig. 4. *The relationship between last winter's age and length* (●) *in migratory char.*

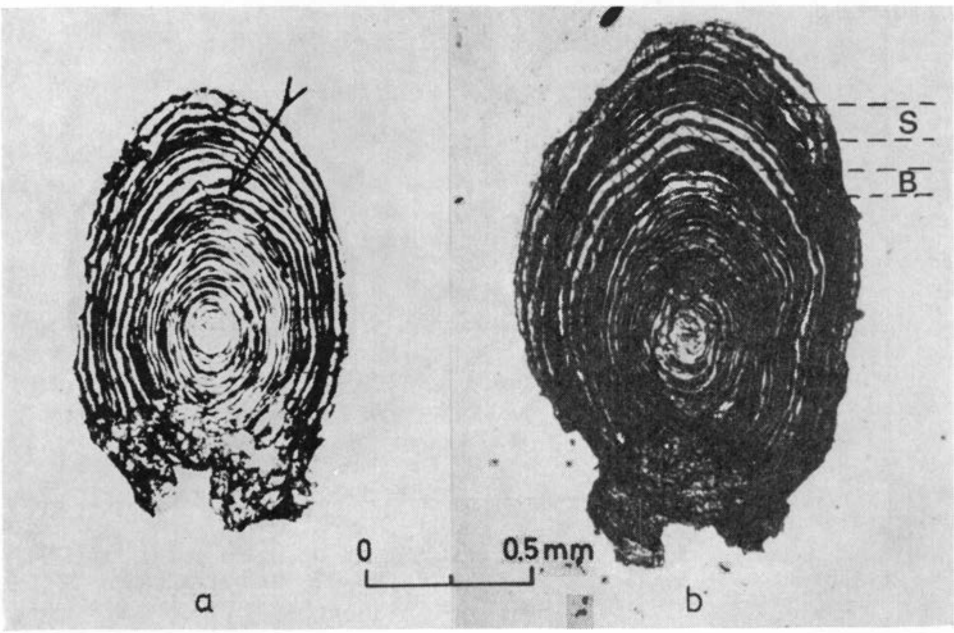


Fig. 5. a) *Scales from migratory char where transition from fresh- to saltwater is clearly seen* (*arrow*). b) *Scales from migratory char where a "brackish water zone"* (*B*) (*see text*) *represents the first sojourn outside freshwater. The next summer zone* (*S*) *represents a true sojourn in the sea.*

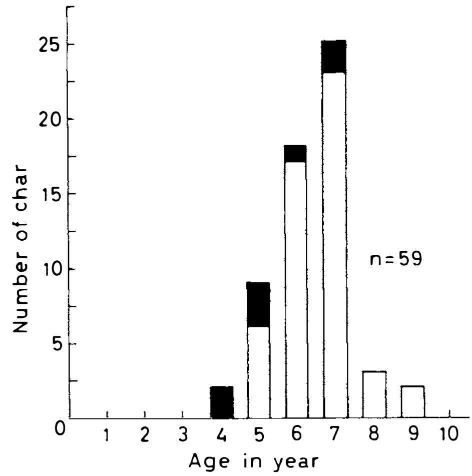


Fig. 6. *Age at first seaward migration calculated on the basis of scales and otoliths. Black columns = char with "brackish water zones" (see text) in the scales.*

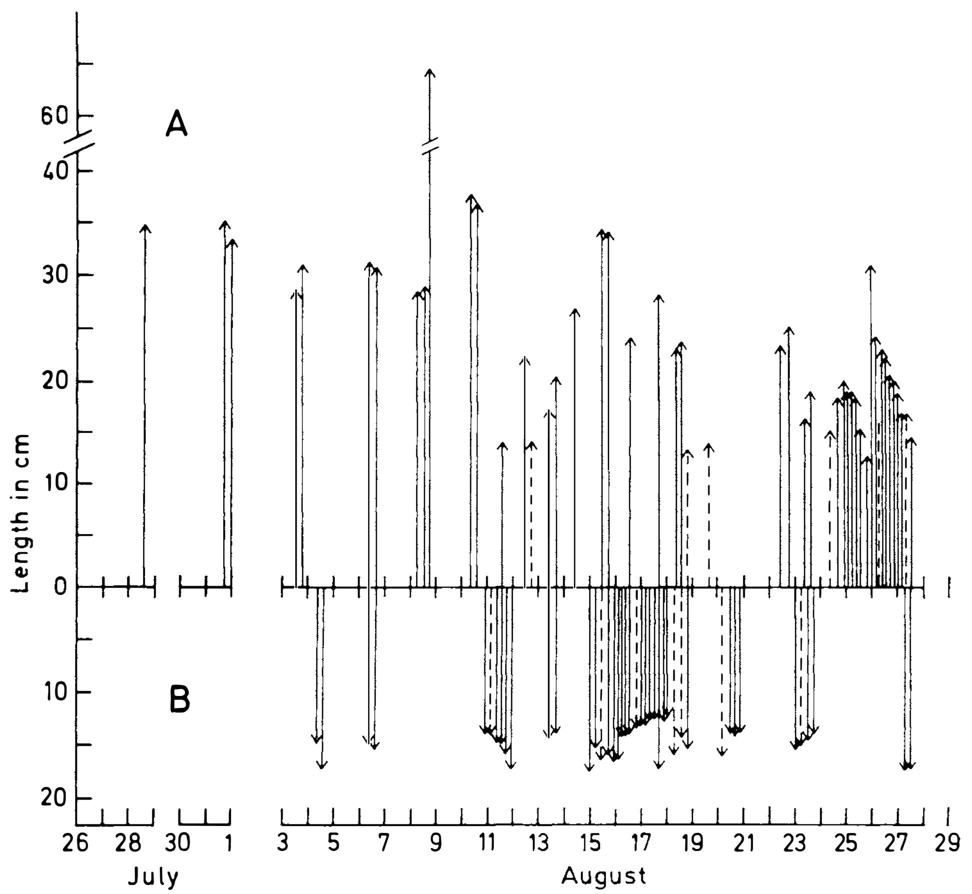


Fig. 7. *Length on date of capture of upstream migrants (A) and downstream migrants (B), char caught by trapping in Revelva 26–29 July, 30 July–1 August, and 3–28 August, 1963. The dotted arrows represent small char tagged on their way downstream and later recaught on their way upstream again.*

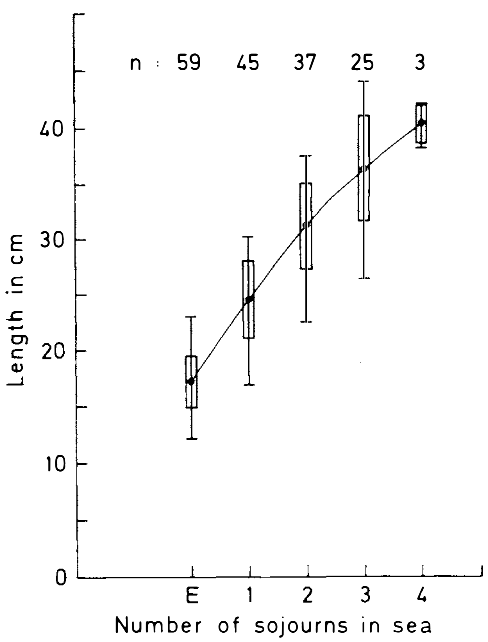
freshwater. This zone is here called "brackish water zone" and is included in the saltwater zones.

Fig. 6 illustrates the age of 59 char at their first seaward migration. Two migrated for the first time when 9 years old, for both these the 8th year zone in the otoliths was very narrow.

Migration. — Due to climatic conditions exact data on migration times could not be obtained.

In an aborted attempt to close Revelva at the beginning of July 1963, two shoals of smolt (9 and about 20 fish) were seen on the upper side of the barrier. Later in the first half of July, smolt were, on several occasions seen far down the river and in the mouth of the river. Between 26 and 29 July, 30 July and 1 August, and 3 and 28 August, Revelva was closed by a barrier with two traps. The length of the trapped fish and the date of catching are found in Fig. 7. During the mentioned period of time, 33 pre-smolt were tagged on their way downstream. Five of the tagged fish were caught again in the upstream trap within the first six days, while one was caught 11 days later. Based on scale calculation the growth rate of char during their first sojourn in the sea could be estimated to from 2.5 to 11.3 cm.

Of the 48 char caught in the upstream trap (Fig. 7) only three were clearly spawners (31 July, 8 and 10 August). During net fishing in Revvatnet on 12 and 14 August, 10 migratory char with lengths of more than 34 cm were caught, four in stage III and three in stage IV. In 1962 the main upstream migration of mature char took place between 18 and 24 August. Both spawners and non-spawners were caught simultaneously.



← Fig. 8. *Average yearly growth rate (± S. D. and max. and minimum values) after first seaward migration (E) in migratory char.*

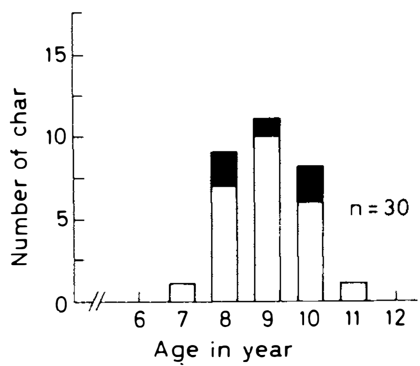


Fig. 9. *Age at first spawning in migratory char. White columns = decision on basis of otolith imprints. Black columns = decision on basis of degree of maturity. (First time spawners).*

Table 2

Gonadal maturity in migratory char, otolith imprints show earlier spawning

Year	Date	Stages of maturity II	III	IV	V	Total
1962	15/8–26/8	2	4	3	2	11
1963	8/8–26/8	–	4	2	1	7
1964	2/8–24/8	4	1	2	–	7
Total		6	9	7	3	25

Growth after first seaward migration. — The growth of char after the first seaward migration is illustrated in Fig. 8.

Age at first spawning and spawning frequency. — The age of 30 char at the moment of sexual maturity is given in Fig. 9. Most of the char spawn for the first time two or three years after the first migration. By calculation from scales the least char length at this time is estimated to be about 32 cm.

Table 2 shows the gonadal maturity of char that have spawned before. At least the 6 char in stage II, all taken after 12 August, should not spawn in the present season. In the otoliths from some char a few broad zones were observed between narrow spawning zones.

NON-MIGRATORY CHAR

Age and growth. — The relationship between age and total length of 78 char is illustrated in Fig. 10. Because none of the "young char" have been in saltwater they are all included here. Four small non-migratory char (3 males and 1 female) were all spawners, the only ones in group II, non-migratory char, caught in Revelva.

Age at first spawning and spawning frequency. — The age of 43 char at the moment of sexual maturity is given in Fig. 11. The four small non-migratory char caught in Revelva had an age at sexual maturity of respectively 6, 6, 8, and 9 years.

Table 3

Gonadal maturity in non-migratory char, otolith imprints show earlier spawning

Year	Date	Stages of maturity II	III	IV	V	Total
1962	20/8–28/8	5	3	3	2	13
1963	12/8–16/8	1	5	1	–	7
1964	2/8–24/8	11	8	1	1	21
Total		17	16	5	3	41

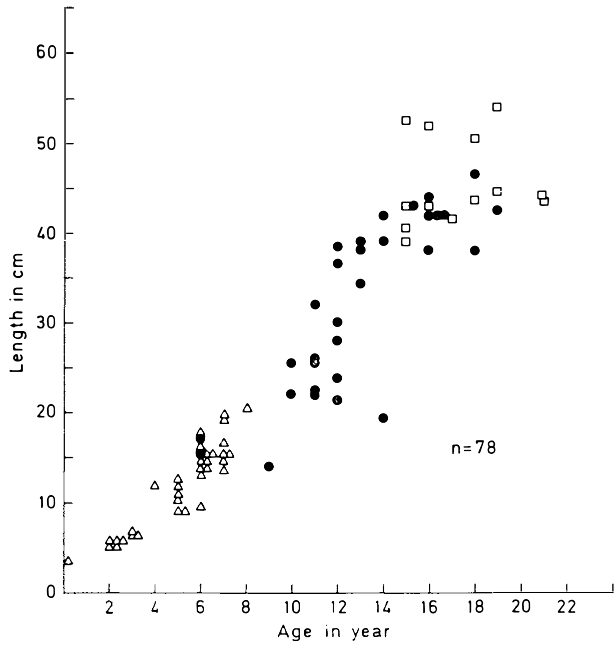


Fig. 10. *Relationship between age and total length in young char* (△), *non-migratory char* (●) *and non-migratory char of minimum age* (*1962 material*) (□).

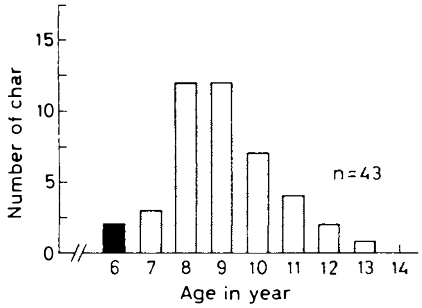


Fig. 11. *Age at first spawning in non-migratory char. White columns = decision on basis of otolith imprints. Black columns = decision on basis of degree of maturity.* (*First time spawners*).

Table 3 shows the gonadal maturity of char that have spawned before. In 1964 only one char (stage II) was caught on 2 August, the others on 22–24 August. At least the 17 char in stage II should not spawn in the present season. In the otoliths from some char single broad zones were observed between narrow spawning zones.

Discussion

The relatively sparse material (155 char, Fig. 3) is mainly due to two causes: 1. The conditions for production in Revvatnet are so limited that each age-group of char is relatively small, and 2. intense fishing earlier has resulted in most of the fish in the longer length groups being fished out before the study began.

The age distribution of the char population in the lake changes greatly according to the down- or upstream migrations. Within the periods covered by the investigation (July–August) practically all the fish which had been in the sea migrated up again.

The difference in the mesh size of each of the nets (Table 1) was so little that it must be presumed that the composition of the catch was representative for the mesh size covered (10–45 mm). The traps caught all fish longer than 12.5 cm (Fig. 3). The difference in length distribution of migratory char caught in nets and those caught in traps may be caused by two factors: 1. Most spawning migratory char were caught in 1962 and 1964 when the traps were not mounted. 2. In 1963 most of the spawning fish migrated upstream in some of the periods when the barrier was broken down.

On the whole the material seems to give a good picture of the stock in the watercourse during the period of investigation.

MIGRATORY CHAR

Age and growth. — Fig. 4 shows wide variation in lengths of char in the age groups from 6 to 10 years. This is a direct consequence of the great difference in age (4–9 years) at the first migration (Fig. 6). Most fish migrated for the first time between the ages of 5 and 7 years, thus it is presumed that the length values in Fig. 4 are only representative of the age groups 8, 9, and 10 years. The earlier age groups still contain fish in the freshwater (young char) which are not included in this figure.

In the present material char older than 10 years are poorly represented (Fig. 4). It seems unlikely that this should result from migratory char of this age in Revvatnet having a naturally high death rate. The main reason is more likely to be that earlier heavy fishing has been directed at fish over 40 cm in length.

Age at first seaward migration. — Smolt migration can take place at any time between the ages of 4 and 9, but most (88.1 %) migrate between the age of 5 and 7 years (Fig. 6). The two 9-year olds, with the narrow 8th year zone in the otoliths, had possibly spawned the year before migration. Both fish which migrated as four-year olds had "brackish water zones" on the scales (Fig. 5b). This zone probably represents shorter periods in brackish water possibly after a passive movement downstream in Revelva during the summer season (discussed later). This points to the fact that the first positively directed downstream migration takes place at 5 years of age.

DAHL (1926) states that smolt migration on Svalbard takes place at the age of 2–4 years (Table 4). His age determination, however, was taken from scales and is therefore underestimated by a minimum of two years (GULLESTAD 1974); taking this into account, results from Revvatnet agree well with those of DAHL.

Table 4

Age at first seaward migration in char from different localities in the arctic. Grainger's age estimations are justified.

Authors	Area	Smolt age	Majority of smolt (age)	Smolt age based on
DAHL 1926	Svalbard	2–4	2–3	Scales
GRAINGER 1953	Baffin Island	4–6	–	Age (otoliths) of young char
NIELSEN 1961	Greenland	3–6	4–5	Age (otoliths) of young char
NORDENG 1961	North-Norway	3–6	4	Scales and otoliths
SWAN 1965	North-Norway	–	5–6	Scales and otoliths
GULLESTAD (this paper)	Svalbard	4–9	5–7	Scales and otoliths

One of the main reasons why others operate with lower migratory ages in other areas is probably the fact that fresh-water nutrient conditions there are generally better than those found in Svalbard.

Migration. — Observations of smolt at the beginning of July 1963 indicate that an active seaward migration was still going on at this time. In contrast to this definite smolt migration we also probably have a random nutritional migration. During the summer young char (12–17 cm), in search of food move slowly downstream towards the river mouth (Fig. 7). Most of them are able to stand the transition from freshwater to seawater, while some of the smallest turn after a short while and swim upstream again (e.g. the five fish caught again straight away). That continual first time migrations which are constantly going on throughout the summer explains the great variation in breadth of the first sea zone on the scales (2.5–11.3 cm).

A short period outside freshwater gives the fish very little chance of benefitting from the good nutritional possibilities. This can explain the formation of the earlier mentioned "brackish water zone" in the scales of some fish. This zone is made up of two to three sclerites the breadth of which and the distance between them being about half of those which represent periods in seawater, but even larger than these representing fresh water periods. It is most likely, therefore, that they have been formed during a shorter sojourn in brackish water.

The random migration of young char which takes place throughout the summer, probably terminates towards the end of August (Fig. 7). Autumn appears quickly, and the catch in the downstream trap showed a rapid diminishing tendency, while on the other hand a greater number of char, with only one stay in the sea, were now being caught in the upstream trap.

From the upper part of Fig. 7 it can be seen that immature char travel upstream throughout the entire period, and it looks as though the smallest are the last to go upstream. The catch of spawners in Revvatnet on 12 and 14 August indicates that these char must either have come up before the barrier became effective on 26 July or in the periods 29–30 July or 1–3 August, when the barrier was broken by flood waters. These together with the fact that only three char, which should spawn the same season, were caught in the upstream trap, show that spawning migration in 1963 took place before 3 August. The different phases of migration probably vary according to the summer climate. The cold summer season of 1962 was probably the reason why the main upstream migration of spawners this year first took place between 18 and 24 August. Hunters overwintering in the area reported that upstream migration by spawners usually begins at the end of July or at the beginning of August, and lasts for about two weeks.

Growth after first seaward migration — The gradually decreasing yearly growth (Fig. 8) is a direct consequence of certain fish beginning to spawn two to three years after the first migration. The figure gives an indication of growth possibilities in seawater, and when similar information is available from other arctic localities it will be possible to discuss the generally accepted postulation that sea growth for char having spent their first years in a cold watercourse is greater than for those beginning life in a warmer watercourse.

Age at first spawning and spawning frequency — The minimum age registered for sexual maturity is 7 years (Fig. 9). DAHL (1926) indicated a minimum age of 5 years for migratory char in Svalbard. Again, if the fact that scales have been the basis for age determination is taken into account, and a minimum of 2 years added (GULLESTAD 1974), we arrive at a minimum age of about 7 years for sexual maturity, making the Revvatnet results comparable with those of DAHL. In Salangen, NORDENG (1961) proved sexual maturity between the ages of 4 and 8 years, i.e., three years earlier than for char in Svalbard. This can be due to better nutritional possibilities in freshwater in Salangen resulting in most of the smolt migrating seawards at 4 years of age, about 2 years earlier than in Revvatnet (Table 4).

Hunters in the area, however, recounted catching both spawners and char which had spawned in nets at the southern end of the lake around mid-September. Whether these were migratory or non-migratory char they could not tell. Until more information is forthcoming, therefore, we must presume this to be the spawning time for both populations.

A spawning cycle of more than one year is indicated by among others SPRULES (1952) and GRAINGER (1953). This conclusion is based on the fact that there were non-spawners among the larger ascending char.

NORDENG (1961) discusses these conditions and indicates that these non-spawners are sexually immature, which was the case in Salangen. NORDENG believes therefore that this is, in general, no basis for a perennial spawning cycle.

In Revvatnet also, spawners and non-spawners are mixing during upstream migration. There are two categories of non-spawners, immature char (as shown in Salangen), and char that have spawned earlier (Table 2). The 6 char with stage II sexual organs that have spawned earlier, show that a spawning cycle of more than one year, at least for some individuals, occurs in Revvatnet. It is most unlikely, however, that this is the rule for all migrating char. Observations of decided broad zones occurring within a series of narrow spawning zones in some fish indicate that this takes place only in certain years and in a limited number of fish. Poor climatic conditions may perhaps be the reason.

NON-MIGRATORY CHAR

Age and growth. — Up to an age of five to six years (represented by young char) migratory and non-migratory char live under similar conditions (Fig. 10). From then on growth is slower for non-migratory char because of the sparse nutritional conditions in freshwater. Fig. 10 shows a relatively great increase in length in char of 10—14 years of age. Normally a reduction in growth rate could be expected in these age groups since sexual maturity for most of the non-migratory char is reached between 8 and 10 years of age (Fig. 11). Therefore the increase in growth rate can only result from better nutritional conditions. In some of the largest non-migratory char, cannibalism has been proved. To what degree the transition to cannibalism accounts for the increase in length is difficult to say however.

The four small spawners (Fig. 10) may belong to the non-migratory population in Revvatnet. They may also be part of a special small-sized population which is stationary in Revelva, or they can be young of migratory char which spawn before migration, as has been proved from Salangen (NORDENG 1961).

Age at first spawning and spawning frequency. — Sexual maturity may be reached at an age of 6 to 13 years (Fig. 11). In Salangen NORDENG (1961) has arrived at an age of between 2 and 8 years for sexual maturity in non-migratory char. One of the reasons why the non-migratory char in Revvatnet are, on the whole, older when they spawn for the first time is probably that they live under poorer nutritional conditions.

A spawning cycle of more than one year for non-migratory char has been inferred by, among others, SPRULES (1952). NORDENG (1961) has shown it to be mainly a one-year cycle in Salangen. Of his 156 small non-migratory spawners however, he mentions 6 with spawning zones in the otoliths which appear to be of stage II and III maturity at spawning time. Of the 41 non-migratory char in Revvatnet which have spawned earlier there are as many as 17 individuals with stage II sexual organs (Table 3). This shows clearly that a spawning cycle of more than one year exist. It is difficult to decide if this is a common pattern or a correlation with a climatically good or poor summer, but most probably the climatic conditions have a high degree of influence. The 1964 summer was short, well below average. At least 11 of 21 char did not spawn that year.

The extreme freshwater conditions under which the char on these northern latitudes (77°N) live, influence their whole development. The low water temperature, the short nutritional season, and the limited amount of available food, all result, first and foremost in extremely poor growth which is again reflected in the higher age of migration and sexual maturity and the increased duration of life. The more favourable nutritive conditions encountered by the migratory char in the sea means that they usually spawn each year. Non-migratory char, on the other hand, need several years to redevelop their sexual prowess between each spawning.

Acknowledgements

Most of this study was carried out while I was working at the Zoological Institute, the University of Oslo. I would like to thank Norsk Polarinstitutt for financial assistance and practical help. Thanks are also due to field assistant Dr. HANS PETTER GULLESTAD, to Cand. real. HANS-JØRGEN SKAR for critically reading the manuscript, and to Mrs. MARGARET ESPELAND for translating the manuscript into Egnlish.

References

DAHL, K., 1926: Contributions to the biology of the Spitsbergen char. Norske Vid-Akad. Oslo, *Result. norske Spitsb.-Eksp.* **1** (7), 1–12.

— 1943: *Ørret og ørretvann. Studier og forsøk.* 2. utg., 112pp. Oslo.

GRAINGER, E. H., 1953: On the age, growth, migration, reproductive potential and feeding habits of the Arctic char (*Salvelinus alpinus*) of Frobisher Bay, Baffin Island. *J. Fish. Res. Bd. Can.* **10** (6), 326–370.

GULLESTAD, N., 1974: On lack of winter zones in the centre of scales from Arctic Char (*Salmo alpinus L.*). *Norw. J. Zool.* **22**, 141–143.

— *Hydrography, Plankton and Benthos in the Arctic lake Revvatnet, Svalbard.* (in prep.)

KUZIEMSKI, J., 1959: Some results of observations of inland waters on Spitsbergen in summer 1958. *Przegl. geofiz.* **IV** (3–4), 179–197. (Polish with summary in English).

LEA, E., 1910: On the methods used in the herring-investigations. *Publ. Circ. Cons. Explor. Mer.* **53**, 7–174.

NIELSEN, J., 1961: Contributions to the biology of the Salmonidae in Greenland I–IV. *Meddr. om Grønland* **159** (8), 1–75.

NORDENG, H., 1961: On the biology of char (*Salmo alpinus L.*) in Salangen, North Norway. I. Age and spawning frequency determined from scales and otoliths. *Nytt. Mag. Zool.* **10**, 67–123.

— 1971: Is the Local Orientation of Anadromous Fishes determined by Pheromones? *Nature* **233** (5319), 411–413.

SPRULES, W. M., 1952: The Arctic char of the west coast of Hudson Bay. *J. Fish. Res. Bd. Can.* **9**, 1–15.

STEFFENSEN, E., 1969: The Climate and its Recent Variations at the Norwegian Arctic Stations. *Met. Annr* **5** (8), 215–349.

SWAN, M. A., 1965: Age estimation in migratory char. *Salm. Trout Mag.* **175**; 163–166.

Studies of population changes and breeding processes in a colony of Eiders (*Somateria mollissima* (L.)) in Svalbard

Исследования популяционных изменений и процессов размножения в гагачьей колонии на Свальбарде

By KARL HAGELUND[1] and MAGNAR NORDERHAUG[2]

Contents

Abstract

Studies of the breeding biology of a colony of eiders (550–600 breeding pairs) were carried out at Kapp Linné, Spitsbergen, in 1969–70. The number of individuals in the colony was greatest at the beginning of the egg-laying phase, during which about 60% of the population were males. By counting the number of males on land during this period, the population size of the colony can be established without causing too much disturbance. The males gradually left the colony during the early stages of incubation.

Egg-laying appears normally to take place so late that it is little affected by snow. However, egg-laying starts somewhat later during a late thaw, giving rise to a well-synchronized breeding process.

Average incubation was 24–25 days. The shortness of this period should be considered as an adaption to the brief nesting season and the relatively high numbers of predators in Svalbard. The time of incubation was found to be independent of the size of the brood. During incubation, the average weight of the eggs dropped from 104.8 g to 91.8 g (12.4%). At the beginning of the hatching phase, a marked invasion of the colony by non-breeding females was observed. Within a period of 9 days, 80% of the nests had hatched. The corresponding number of the

[1] Fylkeshuset, 3100 Tønsberg.
[2] Miljøverndepartementet, Myntgaten 2, Oslo-Dep., Oslo 1.

broody females started nesting within a period of 10 days. Transfer of the young from nest to sea took place in flat terrain, often by way of fresh-water ponds. Movement into the sea invariably took place from sandy shores. Females and juveniles subsequently left the area within the short period of 2–3 days.

Аннотация

Биология размножения гагачьей колонии, насчитывающей 550—600 гнездящихся пар, исследовалась на мысе Kapp Linné на о. Шпицберген в 1969—1970 гг. Число особей в колонии оказалось наибольшим в начале фазы откладки яиц, в течение которой самцы представляли собой 60% популяции. Подсчитывая находящихся на берегу в этот период самцов, можно было установить величину популяции, не существенно мешая птицам. Рано во время насиживания колонию постепенно покидали самцы.

Откладка яиц, кажется, нормально происходит так поздно, что на нее мало влияет снежный покров. Однако она начинается позже при позднем таянии снега, что приводит к весьма синхронизированному процессу размножения.

Среднее насиживание длилось от 24 до 25 суток. Краткость этого периода следует рассматривать как приспособление к краткому гнездовому сезону и сравнительно частому на Свальбарде подверганию гнезд хищничеству. Было установлено, что период насиживания не зависит от числа птенцов в выводке. Во время насиживания средний вес яиц снизился от 104,8 г до 91,8 г (или на 12,4%). В начале фазы вывода птенцов наблюдался заметный наплыв негнездящихся самок в колонии. За девятидневный период птенцы были выведены в 80% гнезд. Сответствующее число самок начинало гнездование в течение 10 дней. Перевод потомства с гнезда на море происходил через плоскую местность, часто через пресноводные лужи. Спуск птенцов на воду непременно происходил с песчанистого берега, через 2—3 дня после чего и самки и детеныши покидали область.

Introduction

The eider duck (*Somateria mollissima*) is the *Anatidae* species occurring in the greatest numbers in Svalbard. It nests in colonies and represents an important link between the maritime and terrestrial ecosystem of the region. In 1968 studies were set in motion by Norsk Polarinstitutt to study population size and breeding conditions of the eider in Svalbard as a means to an improved and more systematic management of the eider in this area. During a stay at Kapp Linné in 1968, it was found that the eider colony there presented a good subject for study of the breeding biology under optimum conditions (NORDERHAUG 1968 and 1970). These studies were carried out in 1969 and 1970 (HAGELUND 1973), and parts of the observations made form the basis of the present survey.

Description of the area

Field work took place at Kapp Linné (78°4'N, 13°38'E) at the mouth of Isfjorden, Spitsbergen (Fig. 1). The area is the northwestern corner of the coastal plain, Isfjordflya, forming the west coast of Nordenskiöld Land. The plain, a permafrost area, is partly covered by ponds and freshwater lakes. The coastal line consists partly of rocks, partly of sandy beaches.

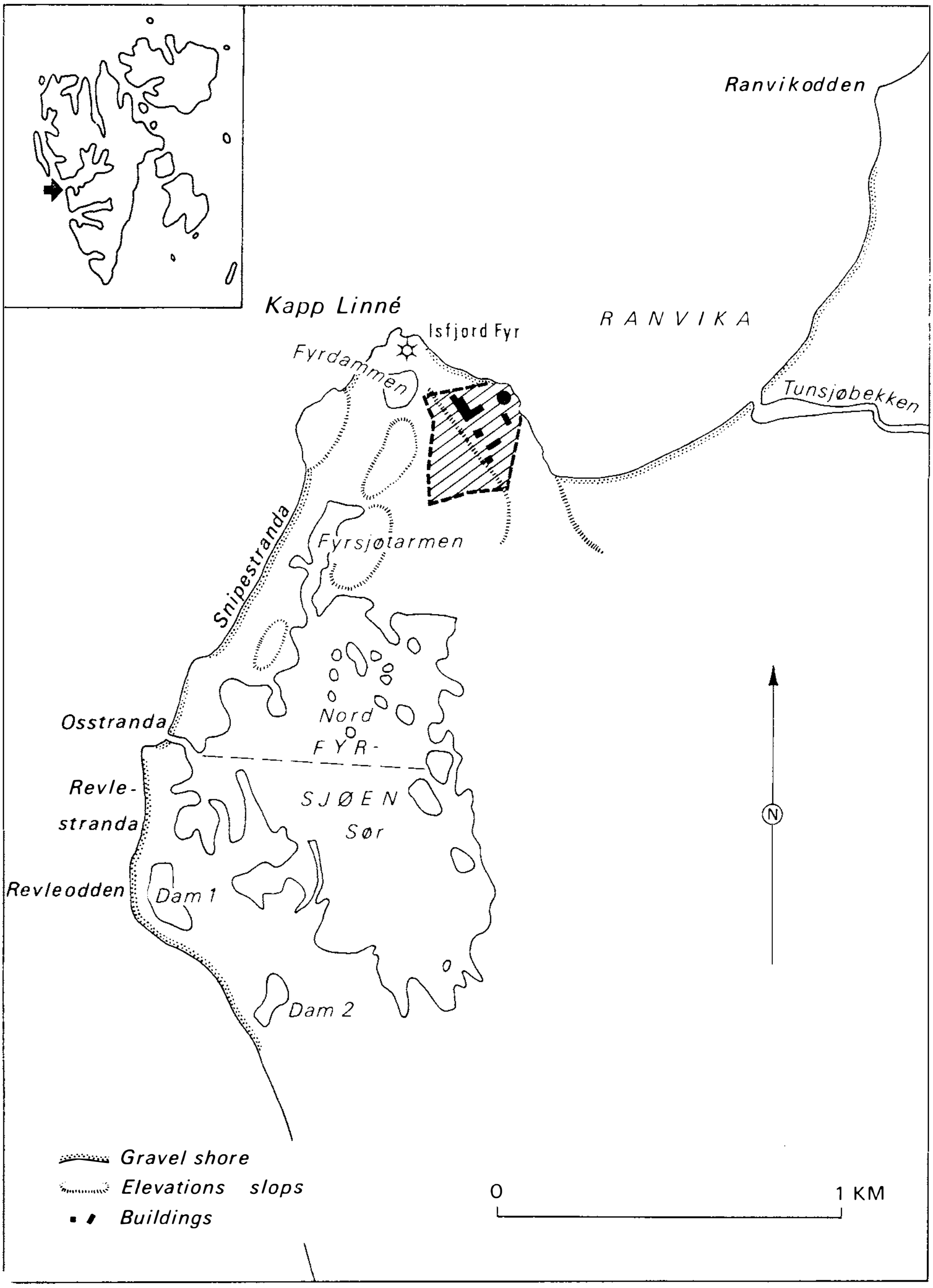


Fig. 1. *Diagram of Isfjord Radio and immediate vicinity. Shaded areas show limits of the eider colony.* Диаграмма радиостанции Isfjord Radio с непосредственной окрестностью. Штриховкой обозначены пределы гагачьей колонии.

In 1933 a meteorological station was established at Kapp Linné. This station (today a combined meteorological and radio station) has been in operation since that time, with the exception of the period of the second world war. The Kapp Linné area is shown in Fig. 1, which also gives the local place-names mentioned in this paper.

Vegetation in the area is typical high Arctic. SUMMERHAYES and ELTON (1923, 1928) classify the Kapp Linné area into the Dryas zone, and the local flora could be classified as "raised beach" and "fjaeldmark" types. Dryer areas are barren or covered by mosses, lichens and grass. In other parts, *Dryas octopetela*, different species of *Saxifraga* and *Luzula*, and *Salix polaris* are dominant.

Areas close to fresh water are dominated by moss communities, consisting of the *Calligeron* and *Drephanocladus* species, with a fairly prevalent influx of grass species. Areas close to the coastline are more or less covered by *Puccinella phryganodes*. In general, local flora in the Kapp Linné area is relatively rich, due to nutrition from eider droppings, etc.

Mammals in the area include seven species: two species of seal (*Phoca hispida*), (*Erignatus barbatus*) (regularly), the walrus (*Obodenus rosmarus*), and white whale (*Delphinapterus leucas*) (irregularly). The Arctic fox (*Alopex lagopus*) is common during the whole year, and dens are found not far from Kapp Linné. Small groups of Svalbard reindeer (*Rangifer tarandus platyrhynchus*) are seen throughout the year. Polar bears (*Ursus maritimus*) are seen mainly during the winter.

Bird fauna is relatively rich, 55 different species having been observed up to 1971. Most numerous are the eider (*Somateria mollissima*) (550–600 pairs) and Arctic tern (*Sterna paradisea*) (200–300 pairs). The eiders and Arctic terns breed mainly within a radius of about 300 metres from the radio station. Other regular breeders include *Clangula hyemalis*, *Somateria spectabilis*, *Phalaropus fulicarius*, *Calidris maritima*, *Arenaria interpres*, *Stercorarius parasiticus*, and *Plectrophenax nivalis*.

Climate

A factor of importance for the climate in Svalbard in general and on Kapp Linné in particular, is the ocean currents along the coast of the group of islands. Conditions along the whole of the western coastal area are influenced by the northernmost feelers of the Gulf Stream with a consequent supply of warm waters.

Fig. 2 shows average ice limits in the coastal waters off Svalbard which are affected to a great extent by ocean currents in the region. Southerly and southwesterly winds are dominant at Kapp Linné during the summer, often leading to periods of mist and some considerable precipitation. Further, ice from the east is sometimes forced round Sørkapp and carried up along the west coast of Spitsbergen during the summer.

The average annual temperature at Kapp Linné is $-4.4°C$ while the average summer temperature (July/August) lies around $+ 4°$ to $+ 5°C$. Precipitation

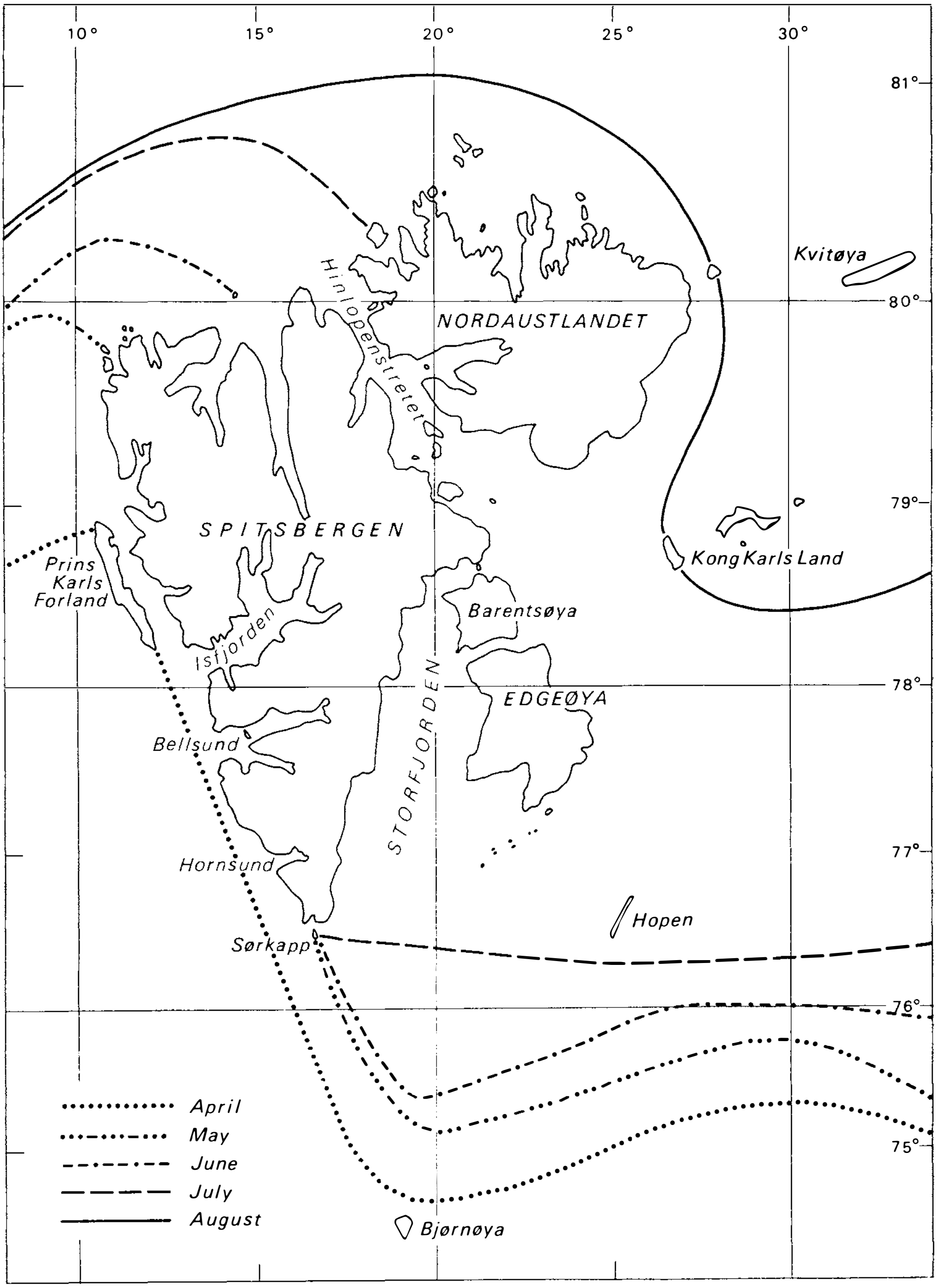


Fig. 2. *Average ice delimitations in Svalbard April, May, June, July, and August from 1919 to 1963. Scale : 1 :5 mill.* (*after* LUNDE *1963*).

Граница среднего распространения льда на Свальбарде в апреле, мае, июне, июле и августе с 1919 по 1963 г. Масштаб: 1:5 000 000 (по LUNDE 1963).

Table 1

Average monthly temperature (°C) at Kapp Linné 1969 and 1970
(HISDAL *1970 and 1972*)

Month	1	2	3	4	5	6
Average 1969	−12.5	−14.7	−19.4	−15.7	−3.6	0.2
Deviation from average 1947–68	−0.8	−3.1	−6.9	−6.8	−0.1	−1.4
Average 1970	−11.6	−14.9	− 9.2	−11.7	−2.6	1.2
Deviation from average 1947–69	0.1	−3.2	3.6	−2.5	0.9	−0.3

Month	7	8	9	10	11	12
Average 1969	4.3	3.5	2.4	−1.1	−8.4	−8.4
Deviation from average 1947–68	−0.2	−0.7	1.5	2.2	−1.8	1.1
Average 1970	4.6	3.9	0.8	−2.9	−9.6	−11.1
Deviation from average 1947–69	0.1	−0.3	−0.1	0.3	−2.9	−1.6

Table 2

Temperature, precipitation and snow depth at Kapp Linné May/August 1969 and 1970
(NORWEGIAN METEOROLOGICAL INSTITUTE *1970 and 1971*)

	Year	May	June	July	August
Average air temperature °C (13.00 hrs.)	1969	−2.7	1.0	4.7	3.9
	1970	−2.7	1.6	5.0	4.3
Precipitation, total in mm	1969	12.1	6.2	16.1	105.4
	1970	21.4	89.1	29.5	85.0
Snow depth in cm (monthly average)	1969	51	20	—	—
	1970	5	1	—	—
Snow cover, scale 0–4	1969	4→3	3→1	1→0	—
	1970	3→1	1→0	—	—

is on the whole slight with an annual mean of under 400 mm, spread fairly evenly throughout the year.

Snow usually lies on the ground from the beginning of October to around the end of May/early June. Wind conditions and local topography lead to considerable variations in the depth of snow. Some data regarding the climate during the seasons of 1969 and 1970 when the main part of the field work was carried out are shown on Tables 1 and 2, from which it is apparent that 1969 was marked by a late spring, but with an otherwise favourable summer. Spring came somewhat earlier in 1970, but during the summer there were periods with strong winds and considerable precipitation.

Changes in size and composition of the eider population during the breeding period

Methods

During the breeding seasons of 1969 and 1970, daily counts at specified times were made at 11 regular check-points beginning at 11 a.m. (Fig. 3). All adult eiders were registered. Roughly 90% of the birds in the colony itself were counted from the windows of the Radio Station prior to beginning the round of checkpoints.

Birds on land and birds on the sea were counted separately. The latter category included all individuals actually on the sea and on the shore up to the high tide-mark. Birds on land included all other individuals, also those on fresh

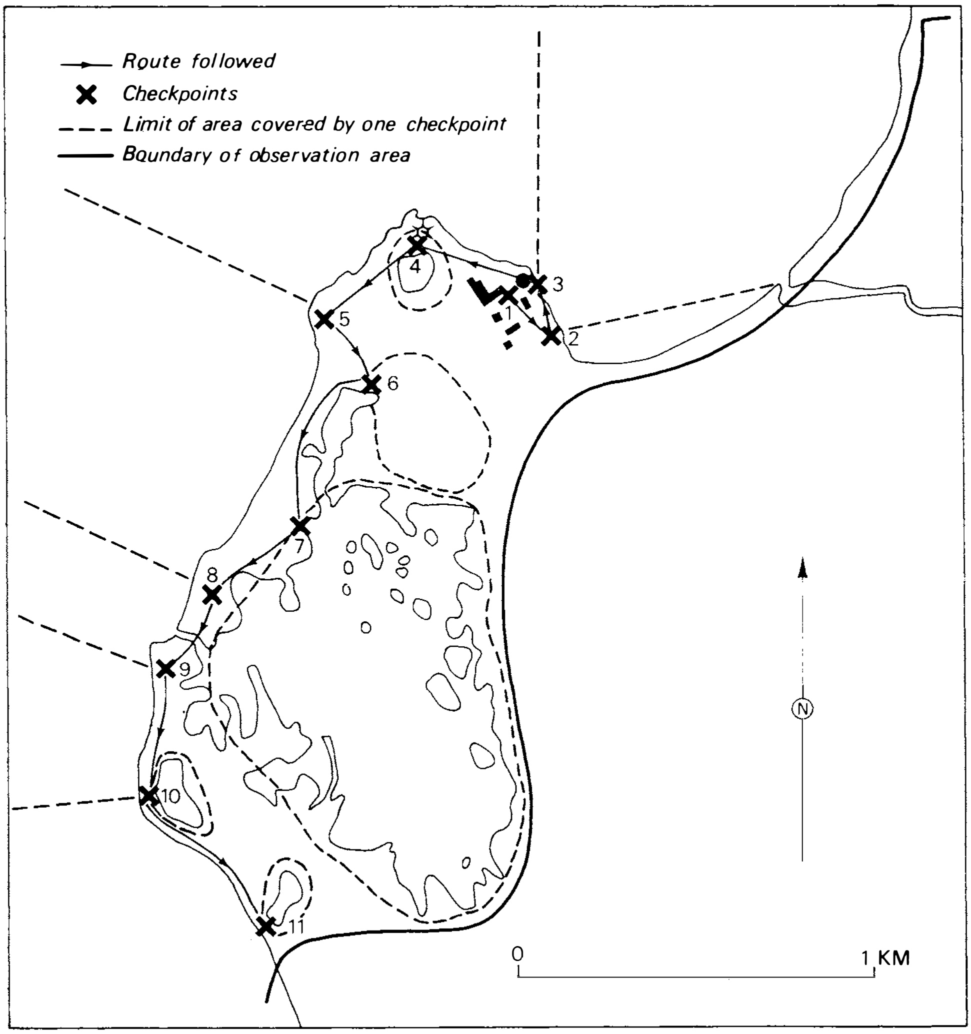


Fig. 3. *Map of observation area 1969–1970.*
Карта области под наблюдением в 1969—1970 гг.

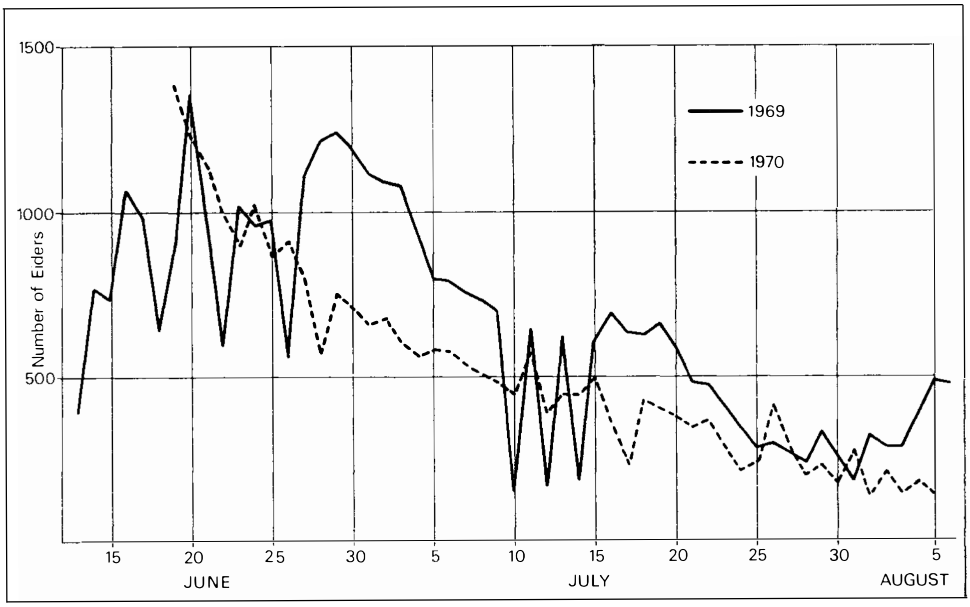


Fig. 4. *Total population in the colony area 1969 and 1970.*
Общая популяция колониальной области в 1969 и 1970 гг.

water ponds. In some cases, due to distance or poor observation conditions, it was possible to record the composition of the sexes only for parts of the population. Where this is the case, comment has been made in the results.

Results

In 1969, observations were carried out from 13 June to 6 August, while in 1970 these took place from 19 June to 5 August. Apart from the initial egg-laying phase in 1970, both breeding seasons were fully covered, recording having been carried out on all but two days. The size of the population, its composition and distribution during the breeding seasons in these two years is shown on Figs. 4—6.

Description of the breeding period

Methods

In order to study the connection between the amount of snow on the ground and egg-laying, the rate of thaw was recorded photographically from the lighthouse in the central areas of the colony. Nesting progress was followed by means of daily checking of the whole colony. Daily checking of the nests began at 3 p.m. and lasted about three hours, checks being taken along roughly the same route each day. This work was carried out without any significant disturbance to the nests by use of quiet movements and neutrally coloured clothing (cf. Cooch 1965). Each nest was marked with a numbered wooden tag, and each

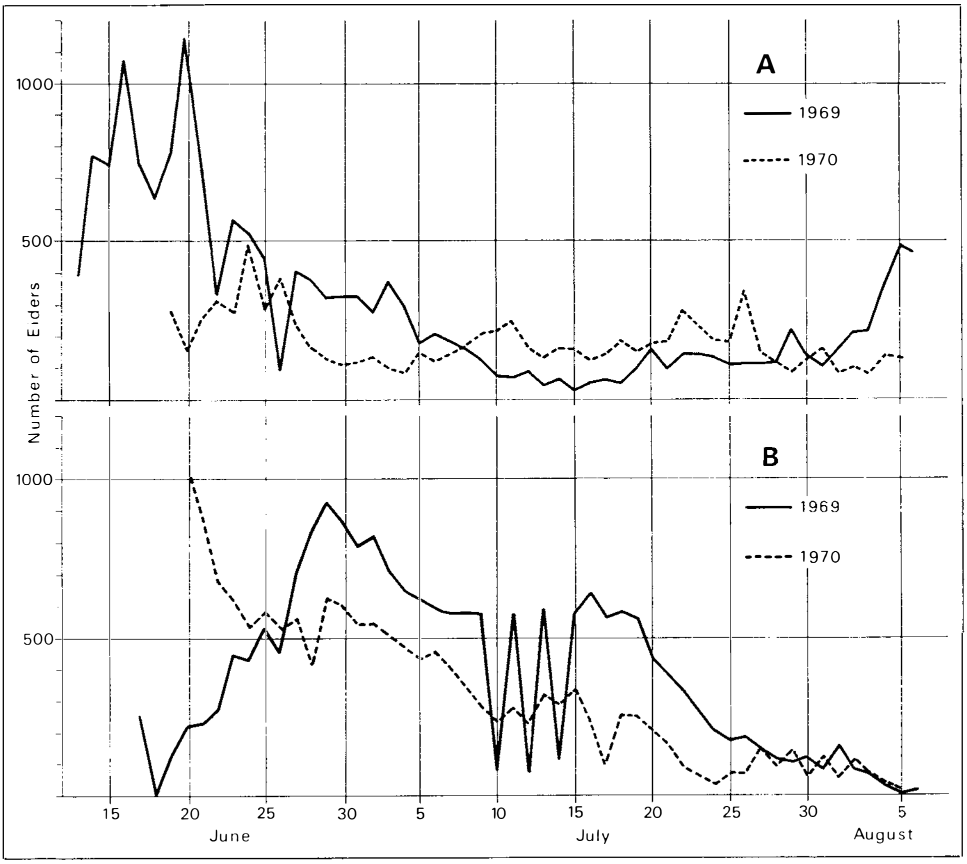


Fig. 5. *Variation in population size on land and sea during the breeding period 1969–1970. A : Population on sea. B : Population on land.*

Вариация численности популяции на суше и в море за гнездовой период 1969—1970 гг. А: Морская популяция. В. Наземная популяция.

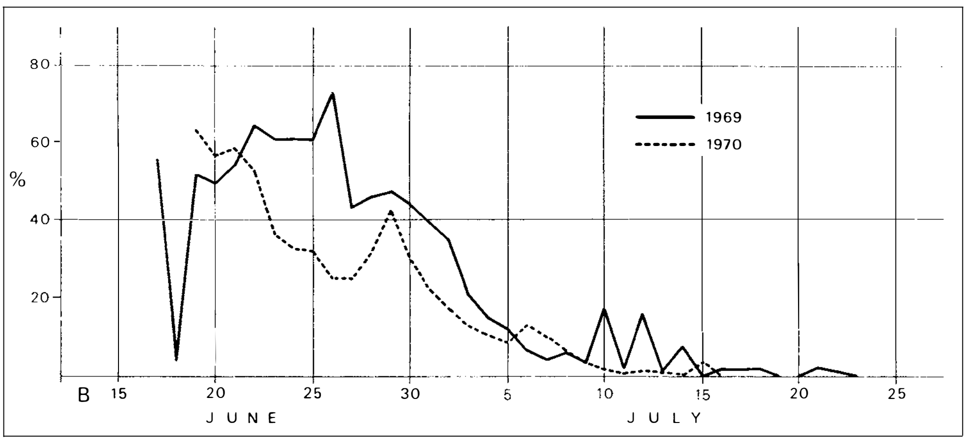


Fig. 6. *Percentage variation in number of males on land in the colony area during the breeding period 1969–1970.*

Процентная вариация числа самцов на суше в колониальной области за гнездовой период 1969—1970 гг.

nest registered was checked throughout the nesting season (until the young left the nest, the nest was plundered, or abandoned for other reasons). Care was taken always to re-cover the eggs where these were found covered during checking, the same applying in cases where a brooding bird was frightened off and left the colony. Most of the females were, however, so thrustful that they merely removed themselves a few metres off and returned immediately to the nest when checking was over. In unfavourable conditions, all the nests were covered.

The egg-laying phase: This included the entire period during which egg-laying was observed. The actual time for the beginning of the egg-laying phase in individual cases was established in the following ways:

A. By direct observation where the beginning of egg-laying was noted.
B. Indirectly by backward calculation when the initial phases of the egg-laying process were not known. These calculations were based on the interval between each egg in the nests under observation (nearly always 24 hours).
C. Indirectly by backward calculation on the basis of the time hatching began (stage 4, below). These calculations were based on the average incubation period for the year in question + the time calculated for egg-laying corresponding to the number of eggs in the brood and an egg-laying interval of 24 hours.

Incubation phase: Studies of the incubation time for the eider were included in the present studies, i.e. the period which elapsed from when the last egg was laid until the last egg was hatched.

Studies were also made in 1969 of the weight-loss of the eggs during the course of incubation. In a series of broods where the commencement of incubation was known, the weight of the eggs was checked at intervals of four days, a spring balance (Pesola) from 0–300 g with a scale of 0.5 g being used.

The hatching phase: This included the entire period when hatching was observed. The following stages were noted on the course of hatching in each individual brood:

1. Cracking marks ("stars") in the shell of at least one egg.
2. Hole in at least one egg, but no chicks actually out of the shell.
3. At least one chick out of the egg and at least one egg at stages 1 or 2.
4. All chicks out of shells.
5. The young leave the nest. Embryonic down visible in nest.

Results

A. *The connection between time of thaw and egg-laying*

Spring came late in 1969. On arrival at Kapp Linné on 12 June, large areas of the breeding grounds were still snow-covered and where the ground was bare, it was so wet that egg-laying had not begun. The various phases of the thaw are shown on Fig. 7 A—C.

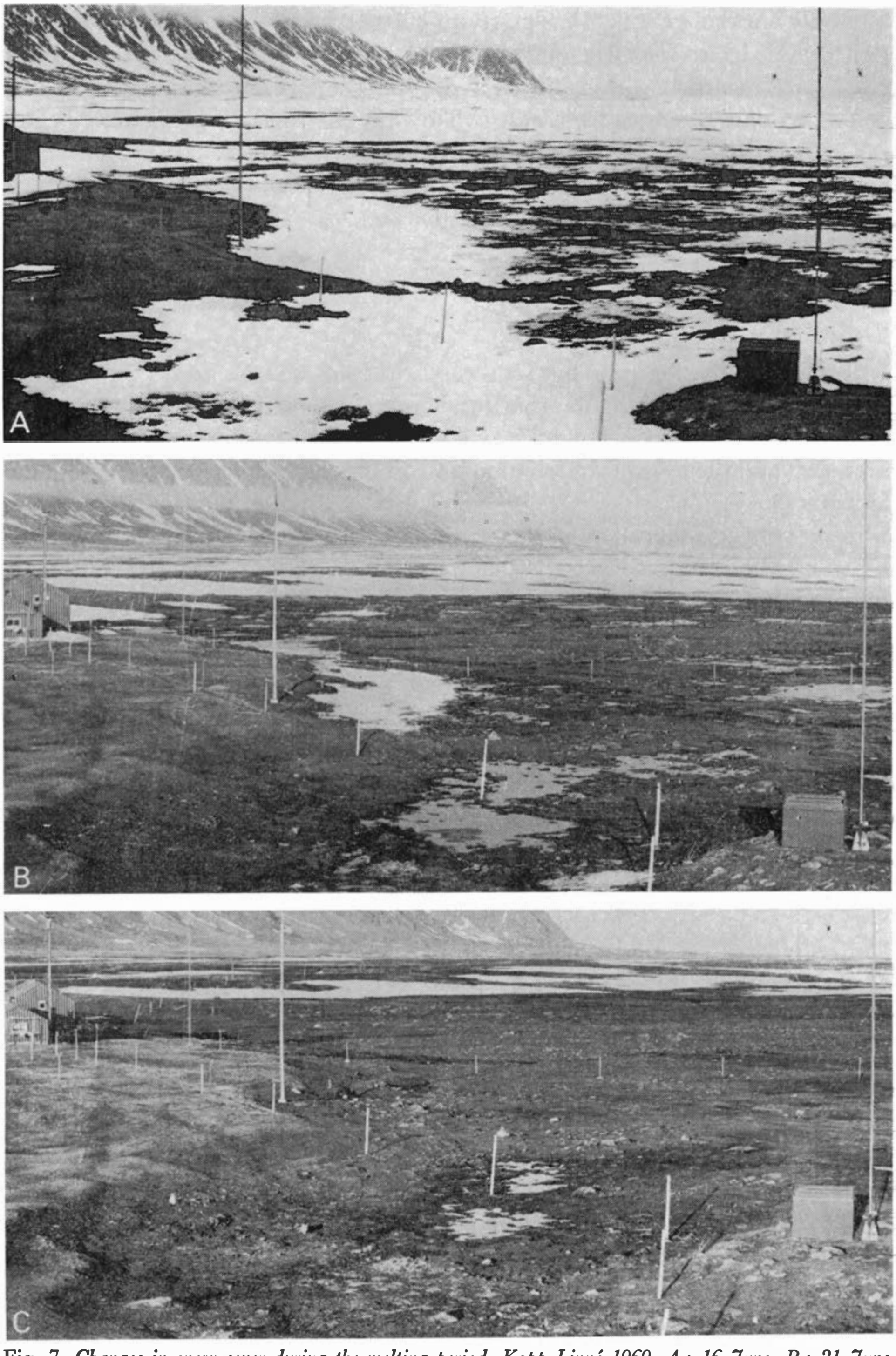


Fig. 7. *Changes in snow cover during the melting period, Kapp Linné 1969. A: 16 June. B: 21 June. C: 29 June.*

Изменения снежного покрова во время таяния на мысе Kapp Linné в 1969 г. A: 16 июня. B: 21 июня. C: 29 июня.

Photos: K. HAGELUND

As only one daily check of the nests was carried out, the resulting material has been grouped into intervals of 24 hours. All broods begun after the previous check were recorded within the same group. These results were later supplemented by data obtained from nests where only the time when hatching began was known (by calculating the time of the egg-laying phase based on average incubation time within the colony). The complete data have been used in describing the course of the egg-laying phase.

B. *The incubation phase*

Average incubation time for 410 broods in 1969 was 24.3 days (approx. 24 days). The average incubation time for 68 broods studied in 1970 was 24.8 days (approx. 25 days). Results on the variations in incubation time in broods of the same size, and the average incubation time in broods of differing sizes, are show on Table 3.

Studies of egg weight-loss in the course of incubation (1969) were begun on 27 June. The results cover 7 broods totalling 33 eggs. Average weight-loss is shown on Fig. 8.

Table 3

Variations in incubation time and average incubation time in broods of varying sizes, 1969 and 1970

Year	Size of brood	Incubation time in 24-hour periods							Average incubation time
		22	23	24	25	26	27	28	
1969	1	1				1			24.0
	2		3	5	7	3			24.6
	3	1	5	31	19	4	2	1	24.5
	4	5	17	85	46	2	4		24.2
	5	2	23	51	34	2	1		24.1
	6	2	9	13	6	3	1		24.1
	7		2	4	8	2	1		24.8
	8			1	1				24.5
	9			2					24.0
1970	1				1				25.0
	2								
	3			4	7	8			25.2
	4	1	1	12	7	4			24.5
	5	1	1	6	6	1	2		24.6
	6			1	2				24.7
	7				2		1		25.7

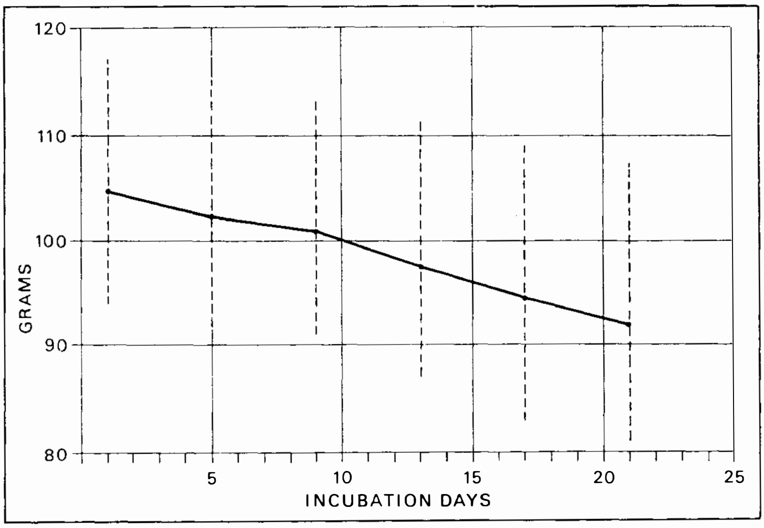


Fig. 8. *Average weight-loss in 33 eggs during the incubation period (1969).*
Средняя весовая потеря 33 яиц за инкубационный период 1969 г.

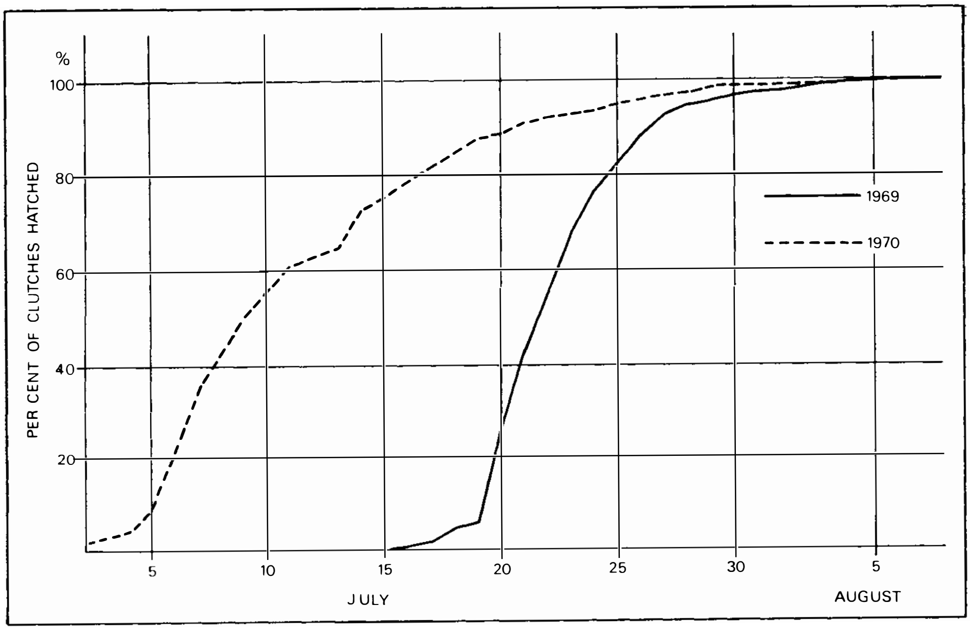


Fig. 9. *Hatching frequency of the colony 1969 and 1970.*
Частота гнездования в колонии в 1969 и 1970 гг.

C. *Hatching phase*

As in the case of the egg-laying phase, these results are grouped into intervals of 24 hours. Fig. 9 shows the course of hatching as hatching frequency (percentage).

The hatching frequency of the colony was chosen in order to illustrate the hatching phase and the connection between this and the egg-laying phase (when egg-laying commenced) – cf. stage 5 above.

D. *Progress after hatching*

Progress after hatching includes observations on routes used when the young were led from the nest to the sea, and their preference for fresh water or the sea. The distribution of young eiders in fresh water and along the shoreline or in the sea was recorded during counts of adult birds. In order to get a picture of how the young gradually left the area, the shore, Fyrsjøen and the ponds were divided into 11 sections, and the number within each section was recorded in addition to the total number of young.

After hatching, the young remain in the nest for only a short time, usually

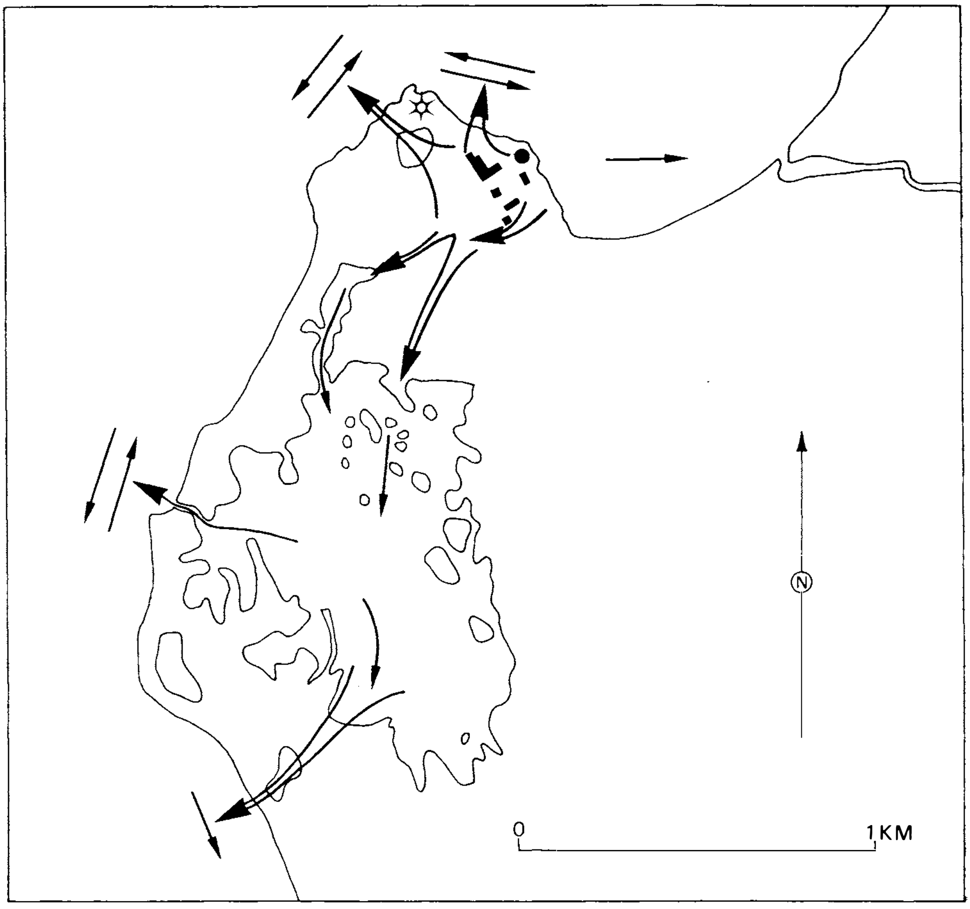


Fig. 10. *Routes chosen for the journey from nest to sea after hatching.*
Маршруты, выбранные для перехода с гнезда на море по окончании гнездования.

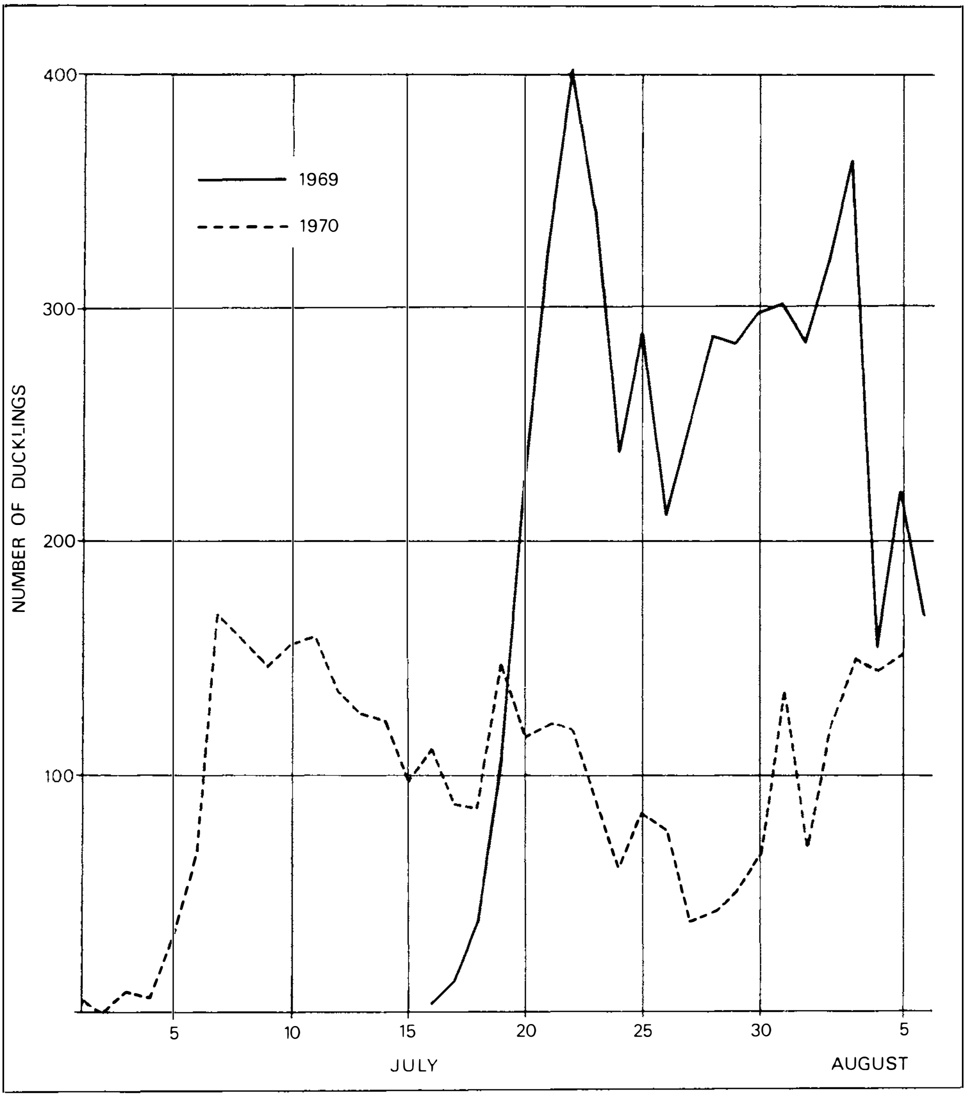


Fig. 11. *Total number of observed eider ducklings in the area, 1969 and 1970.*
Общее число замеченных гагачат в области колонии в 1969 и 1970 гг.

about 24 hours (cf. MILNE 1963), whereafter the mothers conduct the young to the sea, often assisted by a number of "aunts".

The routes chosen for the journey from nest to sea are shown on Fig. 10. The thickness of the arrows indicates the relative importance of the route. Smaller arrows on the same diagram show which direction the juveniles took after reaching the sea.

The total number of young observed each day is shown in Fig. 11.

Discussion

The greatest number of individuals recorded in 1969 was 1,359 of which 779 were males. This indicates a population of around 580 pairs. The highest number of concurrent nesting attempts was 575 and the total number recorded in this year was 682. A certain number of double-brooding is included in the latter figure, as females whose brood was destroyed early in the season re-nested (MILNE 1963). On the basis of the above, the population in 1969 can be established at approx. 600 nesting pairs.

In 1970 the highest number of individuals recorded was 1,391, 64% of these being males, indicating a population of slightly under 650 nesting pairs. The total number of nesting attempts recorded this year was 604, the highest number of concurrent attempts being 481. As the nesting season began early that year, it is possible that many of the nesting attempts at the beginning of the season were not recorded. The number of recorded nesting attempts in 1970 should therefore approximate more closely to the number of nesting pairs than was the case in 1969. It must further be assumed that the highest number of concurrent nesting attempts was lower in this year due to less synchronized nesting.

It appears clear that the number of females in the colony duıing the incubation phase was somewhat lower in 1970 than in 1969 (Fig. 5B). On the basis of the above, the population in 1970 can be estimated at around 550 nesting pairs.

Changes in population in the colony during nesting are best illustrated by the results from 1969, during which year conditions favoured almost fully synchronized nesting. The results from 1970 are less clear, although the same general trend is apparent.

In connection with the material gathered, some further conditions which affected the results should be mentioned:

On 18 June 1969 an appreciable reduction in population was noted. The birds were extremely nervous and exact counts were difficult. On 20 June the highest number of individuals in 1969 was recorded, although some instances of double counting may have taken place. Periods when observation conditions were poor (mainly due to mist) greatly affected the counts of 22 and 26 June and on 10, 12 and 14 July. Moreover, there is a preponderance of males in the figures for these days, as they are more easily recorded.

During bad weather on 28 and 29 June 1970, many individuals on the sea were not recorded, and a number of individuals normally on the sea were on land owing to the rough waters. A further disturbance was the landing of a helicopter on 17 July. Variations in the counting results show therefore a certain connection between poor observation conditions and the small number of individuals recorded.

On the basis of the above, population changes during the breeding process can be summed up as follows:

During the period when the thaw is not sufficiently advanced for nesting to take place, the eider population gathers in offshore waters outside the colony.

There is a marked preponderance of males at this time (about 60% of the population). As the egg-laying phase is succeeded by the incubation phase, the males gradually withdraw from the colony and take to the sea, and the proportion of males in the population on land then falls rapidly. During this time, the proportion of males in the population on the sea can reach approx. 80%. However, the males leave the area fairly soon in order to moult, and their proportion of the population on the sea off the breeding grounds therefore diminishes. Variations in the number of males in the area later in the nesting season is connected with moulting migration over Kapp Linné. A small number of males may, however, moult within the area (cf. BURTON and THURSTONE 1959 and the results from 1970).

The actual incubation phase in the colony is characterized by stable conditions, about 80% of the population being breeding females.

When the hatching phase begins, a new increase in the population takes place in the arrival of a considerable number of new females ("aunts"). These play an active part when the young are led to the sea and later during the growth period. GORMAN and MILNE (1972) give a further description of this situation. HAFTORN (1971) states that these females are not fertile, while MILNE (op.cit.) presumes that some may be older females whose nesting attempts were not successful. Around the nests of females where hatching was taking place, several other females were observed — in extreme cases as many as 36 "aunts" were noted around such nests.

As the hatching phase comes to an end, the colony is deserted and females become dominant in the population on the sea. Most of the females and their young then migrate from Kapp Linné within the course of a few days.

It is probable that the difficulties in calculating the size of an eider colony without unduly disturbing incubation can, in the case of Svalbard, be solved by counting the male population. The fact that the males are easy to count during the time they remain in the colony should in many cases provide an acceptable background in determining the size of the population. This is of course only a rough method, but should provide sufficiently definite information that it is to be preferred to actual counting of the nests which usually leads to plundering by Glaucous gulls. The greatest limitation of this method is that it can only be used during the earliest phases of the nesting process.

Some individual eiders had begun to fly over the breeding grounds already at the beginning of the 1969 survey, and a few of these had landed (prior to 12 June). Most of the area was then covered by snow and a rapid thaw set in during the subsequent period (Fig. 7A–B). When the general thaw set in, activities in the colony increased, and an increasing number of birds remained on the ground for short periods, nearly always in pairs. A similar pattern of behaviour is described by COOCH (1963) and BENGTSON (1972). The reason for no birds being recorded on land before 17 June is linked with the fact that activities in and around the colony at first took place during the "night" while during the day-time the birds remained on the sea.

The first nesting attempts in 1969 were begun on 16 June, and nearly all the population had started nesting in the course of the following 14 days. The full egg-laying phase stretched over a period of 28 days (from 6 June to 7 July) in the 570 nestings where the beginning of egg-laying could be determined. Of the nesting attempts begun in July (the remaining 10%), some must be considered second broods. The 1969 results show that after a late thaw of the breeding grounds, the population gathers in neighbouring areas and that egg-laying starts as soon as the bare patches become sufficiently dry.

When observations were started in 1970, the egg-laying phase was well advanced and nesting had begun in more than 70% of the recorded attempts. In view of this, the whole sequence of egg-laying prior to 19 June was reconstructed. The spring of 1970 came much earlier than in 1969, and egg-laying had probably begun around 1 June. This phase lasted for about 48 days (from 1 June to 18 July) in the 379 cases where the actual time of egg-laying could be determined. At the beginning of the egg-laying phase the covering of snow was 1 cm (Scale 0–4 in the Norwegian Meteorological Yearbook) and the snow depth approx. 2 cm. All snow had disappeared in the course of 12 days (by 12 June), and in 1970 the population was able to get established in the colony without having to wait for the snow to melt and the ground to become dry.

The great difference between the 1969 and 1970 seasons also showed that there is a connection between the extent of the breeding grounds and the melting of the snow on the ground. In 1969 the colony stretched over a considerably larger area than in 1970, which may be explained by the fact that the number of suitable nesting places within a given area is limited just after the snow has melted. As the ground dries off, new nesting places become available. When as in 1969 the egg-laying phase is delayed because of a late thaw, the population is forced to spread over a wider area in order to find suitable nesting places. In seasons with an early spring, as in 1970, the population can find a better choice of sites and the colony can then be concentrated within the most attractive areas.

The average incubation time for the eider in Svalbard has previously not been studied. LØVENSKIOLD (1963) assumes an incubation time of 28 days, without further specification. For eiders in general, incubation is stated as 21 days (COLLETT 1921) up to 30 days (COOCH op.cit.). WITHERBY et al. (1948) and BAUER and BLOTZHEIM (1969) give 27–28 days and 25–26 days, respectively. That such varying figures as 21 and 30 days are stated may be due to differing interpretations of the incubation time.

Table 4 gives a summary of statements concerning the incubation time for eiders.

From Table 4 it will be seen that there is a tendency to a shorter incubation for northerly populations than for those further south. This bears out LACK (1968) who states that this trend applies to ducks in general. BELOPOL'SKII (op.cit.) states that the incubation time for artificial brooding is 24 days. The results of the Kapp Linné studies are close to this figure, which may be taken as an indication that incubation is very effective here and adapted to the short nesting season in Svalbard. Most studies of nesting biology show that the female

Table 4

Average incubation time for eiders

Reference	Locality	Average incubation time	Material
GUIGNION (1968)	St. Lawrence Bay, Canada 48°N	26.0 ± 0.2	57 broods
MILNE (1963)	NE Scotland 57°N	26 (25–29)	61 «
HAFTORN (1971)	Trøndelag 64°N	27.9 (27–29)	10 «
GUDMUNSSON (1932)	Iceland 65°N	28–30	57 «
FLINT (1955)	U.S.S.R. 58°–80°N	25–29	—
BELOPOL'SKII (1961)	Barents Sea coasts c. 70°N	25 (23–27)	—

eider will leave the nest voluntarily during the incubation period only in exceptional circumstances (BELOPOL'SKII op.cit.), (MILNE op.cit.).

As the eider in Arctic regions has little chance of camouflaging its nest in the local vegetation, it must be assumed that the combination of uninterrupted brooding and short incubation time is an adaption partly to the brief nesting season and partly to the threat from egg-eating predators to which the population is exposed.

BELOPOL'SKII (op.cit.) asserts that the duration of incubation depends on the size of the brood. The results of the present studies in no way bear this out. Chi² tests showed that none of the average incubation times for the individual size of brood differs significantly from the average incubation time, calculating each year separately (pm > 0.90).

There is a very marked loss of weight in the eggs during the course of incubation. Average weight loss in the 33 eggs investigated was 104.8 g –91.8g = 13 g, i.e. 12.4% of the average weight at the beginning of incubation. A similar investigation by MILNE (op.cit.) showed a 15% weight loss in 5 broods. MILNE carried out the last weighings nearer to hatching time than was the case in the present studies.

BELOPOL'SKII (op.cit.) shows a corresponding weight loss for 11 eggs of 16.3%. The weight loss during incubation in 2 different incubators is given by BELOPOL'SKII (op.cit.) at 11.2% and 13.2%, respectively.

The aim of the researches on weight loss was to study an alternative method for determining roughly to what average stage in the incubation phase a colony had come, and thereby to reconstruct the course of nesting, by visiting a colony only once. In this way, disturbance is avoided to a far greater extent than when the progress of nesting is followed by regular observations. This is particularly true of Svalbard, where predators can in many places cause considerable damage when the females leave the nest.

Although fuller background material would have been desirable, the weighing method would seem to be usable, on the basis of the present data, in all cases where nesting is fairly synchronized. The method would presuppose weighing of a larger number of eggs and that average weight is used as an indication of how far in the incubation phase a colony had reached. However, the method remains to be tried further and adjustments made to the curve showing average weight loss on the basis of wider background material.

The hatching phase extended over 23 days in 1969 (15 June to 6 August) in the 476 attempts at nesting which were successful. In 1970 the hatching phase lasted for 37 days (2 June to 7 August) in the 315 attempts where the time of hatching was established. On the whole, the hatching phase reflects the egg-laying phase, with a displacement in time of 28–30 days (incubation time of 24–25 days + egg-laying time of 4–5 days).

The young were taken from the breeding grounds to the sea along various routes. Although the site of the nest and distance to the sea was decisive in most cases, the shortest route was not always used. All the routes followed flat terrain where the young could move easily. Movement into the water was always from sandy shores. While the young were on the sea, it was usual to see several of the females (both mothers and "aunts") leading a flock of young from several broods. Such mixing of broods is described further by MILNE (op.cit.) and GORMAN and MILNE (1972) as "crèche behaviour". Daily counts of the population in the area confirm that the chicks leave the colony area shortly after reaching the sea. Movement is both southwards and along the Isfjord. Along these coastal areas many females and young were observed. As there is no other colony of eiders in the region, these must have been individuals from the colony at Kapp Linné. AHLÉN and ANDERSSON (1970) and GULLESTAD (1973) describe a similar migration shortly after hatching in the Kongsfjord district, where the population appears to move out of Kongsfjord and on to the west coast of Prins Karls Forland and the west coast of the Mitrahalvøya.

Researches into the movements of the eider population and the further development of the young were not included in the present studies.

Acknowledgements

We would like to thank the leader of the Isfjord Radio Station for permission to use one of the buildings during the field periods 1968–1970.

We would also like to thank the crew on the radio station for all kindness and help.

References

AHLÉN, I. and Å. ANDERSSON, 1970: Breeding Ecology of an Eider Population on Spitsbergen. *Ornis Scand.* **1**. 83–106.

BAUER, K. M. and GLUTZ VON BLOTZHEIM (ed), 1969: *Handbuch der Vögel Mitteleuropas. III.* Anseriformes. Frankfurt a. Main (Akad. Verl.ges.). 504 pp.

BELOPOL'SKII, L. O., 1961: *Ecology of the sea colony birds of the Barents Sea.* Jerusalem (IPST 125). 346 pp.

BENGTSON, S.-A., 1972: Reproduction and fluctuations in the size of duck populations at Lake Myvatn, Iceland. *Oikos*. **23**. 35–58.

BURTON, P. J. K. and M. H. THURSTON, 1959: Observations on Arctic terns in Spitsbergen. *Brit. Birds*. **52**. 149–161.

COLLETT, R. (v/Ø. OLSEN), 1921: *Norges Fugle. III.* Kristiania (Aschehoug). 415 pp.

COOCH, F. G., 1965: The Breeding Biology and Management of the Northern Eider (*Somateria mollissima borealis*) in the Cape Dorset Area, Northwest Territories. *Can. Wildl. Service. Wildl. Mgmt. Bull.* **2** (10). 68 pp.

GORMAN, M. and H. MILNE, 1972: Crèche Behaviour in the Common Eider *Somateria m. mollissima* (L). *Ornis. Scand.* **3**. 21–25.

GULLESTAD, N., 1973: Noen observasjoner av pattedyr og fugl i Kongsfjordområdet, Spitsbergen. *Norsk Polarinstitutt Årbok* 1971. 59–66.

HAFTORN, S., 1971: *Norges Fugler*. Oslo (Universitetsforlaget). 862 pp.

HAGELUND, K., 1973: Studier av ærfuglens (*Somateria mollissima* (L)) hekkebiologi på Svalbard. *Unpubl. Thesis. Univ. Oslo*. 71 pp.

HISDAL, V., 1970: The weather in Svalbard in 1969. *Norsk Polarinstitutt Årbok* 1969. 129–131.

— 1972: The weather in Svalbard in 1970. *Norsk Polarinstitutt Årbok* 1970. 252–255.

LACK, D., 1968: *Ecological Adaptions for Breeding in Birds*. London (Methuen). 409 pp.

LUNDE, T., 1963: Sea ice in the Svalbard Region 1957–1962. *Norsk Polarinstitutt Årbok* 1962. 24–34.

LØVENSKIOLD, H. L., 1963: Avifauna Svalbardensis. *Norsk Polarinstitutt Skrifter*. Nr. 129. 460 pp.

MILNE, H., 1963: Seasonal Distribution and Breeding Biology of the Eider *Somateria mollissima*, L, in the North-East of Scotland. *Unpubl. Ph.D. Thesis*. Univ. Aberdeen. 235 pp.

NORDERHAUG, M., 1968: Ornitologisk feltarbeid på Svalbard 1968. *Sterna*. **8**. 187–190.

— 1970: Ornitologisk feltarbeid på Svalbard 1969. *Sterna*. **9**. 107–109.

NORSK MET. INSTITUTT, 1970: *Norsk Meteorologisk Årbok 1969*. Oslo. 160 pp.

— 1971: *Norsk Meteorologisk Årbok 1970*. Oslo. 167 pp.

SUMMERHAYES, V. S. and C. S. ELTON, 1923: Contribution to the Ecology of Spitsbergen and Bear Island. *J. Ecol*. **11**. 214–286.

— 1928: Further Contribution to the Ecology of Spitsbergen. *J. Ecol*. **16**. 193–268.

WITHERBY, H. F., C. R. JOURDAIN, N. F. TICEHURST, and B. W. TUCKER, 1948: *The Handbook of British Birds. III.* London (Witherby). 387 pp.

Studies of the productivity of the Svalbard Eider (*Somateria mollissima* (L.)) under optimal conditions

Исследования производительности свальбардской гаги в оптимальных условиях

By KARL HAGELUND[1] and MAGNAR NORDERHAUG[2]

Contents

Abstract

The paper summarizes a study of the productivity of the Eider (*Somateria mollissima*) in Svalbard under optimum conditions.

Studies took place at Kapp Linné, Spitsbergen, 1968–70. During two breeding seasons (1969 and 1970) a colony of 550–600 breeding pairs were checked daily to study egg production, clutch size, predation, and young production.

Average nesting success in the colony for both seasons together was 65.5%. The material from the present study points to a 70% nesting success for the Eider as the maximum to be expected in Svalbard. Average brood size was 4.55 eggs. Average egg loss was 0.50–0.58 eggs per nest. Highest recorded production potential was 2.87 young per nesting attempt. A production result as high as 3 young per nesting attempt should be regarded only as a theoretical figure for Svalbard.

Predation was caused mainly by Arctic fox (*Alopex lagopus*) and Glaucous gull (*Larus hyperboreus*). However, the crew at the radio station are giving a rather effective protection to the colony, together with a colony of Arctic terns (*Sterna paradisea*). Influence of the weather on egg losses is shown in Fig. 4. Predation in the colony in 1969 and 1970 is shown in Figs. 5 and 6.

[1] Fylkeshuset, 3100 Tønsberg.
[2] Miljøverndepartementet, Myntgaten 2, Oslo-Dep., Oslo 1.

Аннотация

Подводятся итоги исследования производительности гаги (*Somateria mollissima*) на Свальбарде в оптимальных условиях.

Исследования этого явления провелись на мысе Kapp Linné (о. Шпицберген) в 1968—1970 гг. Во время двух гнездовых сезонов (в 1969 и 1970 гг.) колония, насчитывающая 550—600 гнездящихся пар, ежедневно наблюдалась с целью изучения производства яиц, числа яиц в кладке, подвергания гнезд хищничеству и производства детенышей.

Средний гнездовой успех колонии для обоих сезонов вместе взятых равнялся 65,5%. Материалы настоящего исследования указывают, что максимальный ожидаемый гнездовой успех свальбардской гаги равняется 70%. Средним числом яиц в кладке оказалось 4,55, а средней потерей яиц с каждого гнезда — 0,50—0,58. Наивысшим отмеченным производственным потенциалом окалось 2,87 птенца по гнездовой попытке. Производственный результат, достигающий 3 птенцов по гнездовой попытке, должен быть рассмотрен только как теоретическая цифра для Свальбарда.

Хищничеством занимались главным образом песец (*Alopex lagopus*) и бургомистр (*Larus hyperboreus*). Однако сотрудники расположенной по близости радиостанции оказывали довольно эффективную защиту так этой колонии, как и колонии полярных крачек (*Sterna paradisea*). Влияние погоды на потерю яиц показано на рис. 4. Результаты хищничества в колонии в 1969 и 1970 гг. приведены на рисунках 5 и 6.

Introduction

In 1968 Norsk Polarinstitutt initiated a study of the eider (*Somateria mollissima*) on Svalbard, and it was found that the eider colony at Kapp Linné presented a good subject for studies of nesting biology, particularly with regard to the influence of predators. Svalbard's only mainland colony nests at Kapp Linné. In 1969–70 the population was approximately 550–600 nesting pairs (HAGELUND 1973), all of which were included in the studies. The aim of the present researches was to obtain a basis for comparison of the optimum conditions for productivity, for an evaluation of the productivity conditions and the influence of predators in other eider colonies in the Svalbard region (NORDERHAUG 1968 and 1970). Observations at Kapp Linné were begun in 1968 and carried on in 1969 and 1970 (HAGELUND op.cit.). Kapp Linné (78°4'N, 13°38' E) lies at the mouth of Isfjord on the west coast of Spitsbergen. A detailed description of the area is given by HAGELUND and NORDERHAUG (1974).

Methods

All nests in the colony were marked and checked daily, following an agreed procedure (HAGELUND and NORDERHAUG op.cit.). In nests where hatching was completed and the young had left the colony, records were made of how many eggs or chicks remained.

In evaluating the individual attempts at nesting, the following criteria were used:

Predators: Number of eggs disappearing between two checks. Not applied in the case of single egg broods as the egg may have been stolen by another female. Such instances were put into the category "unknown".

Desertion: Eggs cold on at least two successive checks, after having been incubated for some time.

Successful nesting: At least one chick hatched and left the nest.

"*Unknown*": All other nesting attempts not coming within the above categories were labelled "unknown".

Fully-laid brood: Where number of eggs in the nest had not increased after three days.

Size of brood at beginning of hatching: Number of eggs in the nest at the last check, prior to Stage 2 of the hatching process (HAGELUND and NORDERHAUG op. cit.).

Number of young leaving the nest: The difference between the size of brood at beginning of hatching and the number of eggs (or chicks) remaining in the nest after the young had left.

Total number of eggs produced: Highest number of eggs recorded in each nest.

Average size of brood: The number of eggs recorded on the daily checks, divided by the number of nesting attempts taking place on the same day (excluding nesting at Stage 2 or the later stages of the hatching phase).

Production of eggs and young

Table 1 gives the figures for successful nesting in the 1969 and 1970 seasons, with a survey of the causes for non-success in individual cases.

Table 2 shows productivity within the colony and the average productivity per brood in 1969 and 1970.

Table 1

Successful nesting in 1969 and 1970

	Year	Successful	Non-successful due to				Total
			Predators	Desertion	Ringing	Unknown	
No.	1969	476	59	52	0	95	682
%	1969	69.9	8.7	7.6	0	13.9	100.1%
No.	1970	314	34	174	5	77	604
%	1970	52.0	5.6	28.8	0.8	12.7	99.9%

Table 2

Production of eggs and young, 1969 and 1970

	Year	Total egg production	Fully-laid	Hatching begun	Young
No.	1969	2783	2194	2010	1876
No. of broods	«	682	492	476	476
Average size of brood	«	4.08	4.46	4.22	3.96
No.	1970	2722	527	1372	1224
No. of broods	«	604	118	314	314
Average size of broods	«	4.51	4.47	4.37	3.89

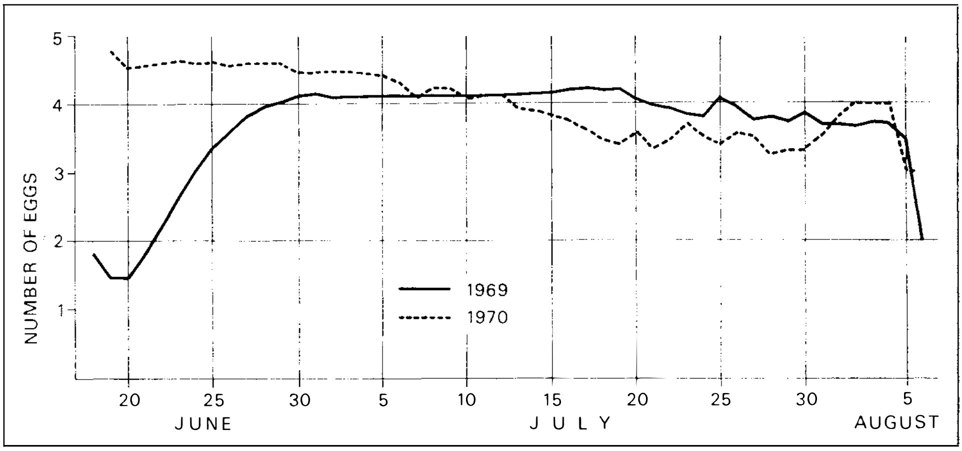


Fig. 1. *Average brood size (based on daily nest checks) during the incubation period, 1969 and 1970.* Среднее число птенцов в выводке (на основе ежедневного наблюдения за гнездами) за инкубационный период в 1969 и 1970 гг.

Table 3

Production of eggs and young in all nesting attempts 1969 and 1970

	Year	Fully-laid	Hatching begun	Young
No.	1969	1870	1794	1696
No. of broods..........	«	413	413	413
Average size of brood ..	«	4.52	4.34	4.11
No.	1970	296	279	262
No. of broods..........	«	68	68	68
Average size of brood ..	«	4.35	4.10	3.85

It was possible in some nests to observe the nesting process from the time the brood was complete until the young left the nest. If the results from these broods alone are taken into consideration, productivity in the colony is as shown on Table 3. Fig. 1 shows the average size of brood for all nesting attempts in 1969 and 1970.

Factors influencing productivity

Biotic factors

Man: The personnel of the Isfjord Radio station play an important part in productivity, being probably the most important positive factor. Firstly, they keep predators such as the Arctic fox and Glaucous gulls away from the colony (the eiders here being completely used to gunshot reports and no longer reacting to them). Secondly, the site of the radio station has indirectly provided many new nesting places in addition to the natural ones found in the area.

In some cases, the presence of man can also have a negative influence on productivity, for instance where timid females are nesting in the busiest parts of the area. Another negative factor is that the Glaucous gulls are attracted by refuse from the radio station. Dogs have sometimes broken loose and caused damage among the nests. Occasional eiders are killed by flying against the radio aerials and guy-wires. Outside visitors can also disturb the nests.

Arctic tern : As Arctic terns are very aggressive towards intruders and predators, they give very effective protection to other species nesting in the area. These aggressive tendencies afford good protection particularly against Glaucous gulls and Arctic skuas. The Arctic tern colony at Kapp Linné was previously put at approximately 600 pairs (BURTON et al. 1960). In 1969–70 it was estimated at 200–300 nesting pairs.

Glaucous gulls : This is a species of predator which utilizes all available sources of food, and eider eggs and young form no small part of their diet in Svalbard. This is also true of Kapp Linné to the limited extent that these predators get the chance. No Glaucous gulls nest in the vicinity of Kapp Linné.

Arctic skua : The species is not numberous at Kapp Linné, although some pairs occur which will take eider eggs if given the opportunity.

Arctic fox : As the eider colony at Kapp Linné is situated on the mainland, it is at constant risk from the depredations of the Arctic fox. The species is found regularly in the area, and together with the Glaucous gull, is the chief predator. One–two pairs occupy dens in the vicinity of Kapp Linné.

Fig. 2. *Typical breeding site close to a small rock for wind shelter.*
Типичное, близкое от небольшой оказывающей защиту от ветра скалы гнездовье.
Photo: K. HAGELUND

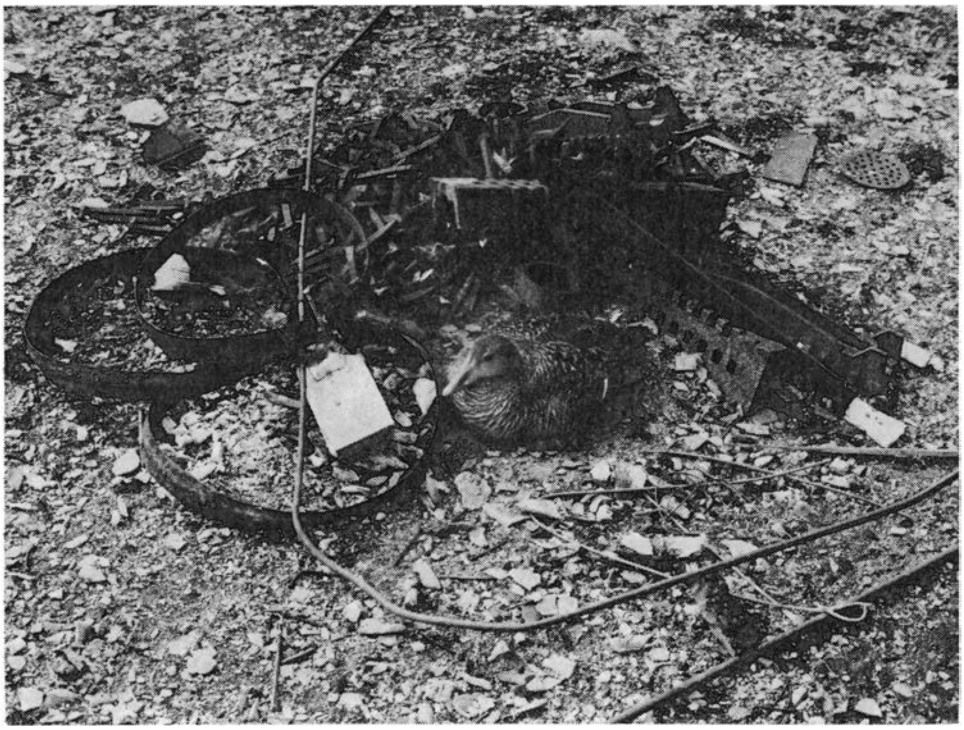


Fig. 3. *Man-made breeding site.*
Сделанное человеком гнездовье.

Photo: K. Hagelund

Svalbard reindeer: One curious fact is that at Kapp Linné reindeer have been seen in the breeding grounds breaking and eating the contents of the eider eggs (crew on Isfjord Radio, personal comment). As reindeer are frequently seen in the area, some individuals get into the colony and accidentally destroy nests or eggs.

Abiotic factors

Nesting places: Eiders usually make their nests close up to a stone or other structure which affords protection against wind and weather (Figs. 2 and 3). The installation of the radio station at Kapp Linné has resulted in a number of new, artificial nesting sites. In the locality, the building itself protects many nests which would otherwise have been exposed. There is also various debris lying around which again provides good nesting places (Fig. 3).

Climatic conditions: In general, it can be considered normal that a number of nests are deserted during incubation time. There is, however, a marked difference in the number of nests deserted in the 1969 and 1970 seasons, and it would seem obvious that there is a connection between the number of nests deserted and the prevailing conditions of wind and precipitation. Data from 1970, illustrating this the most clearly, is given in Fig. 4.

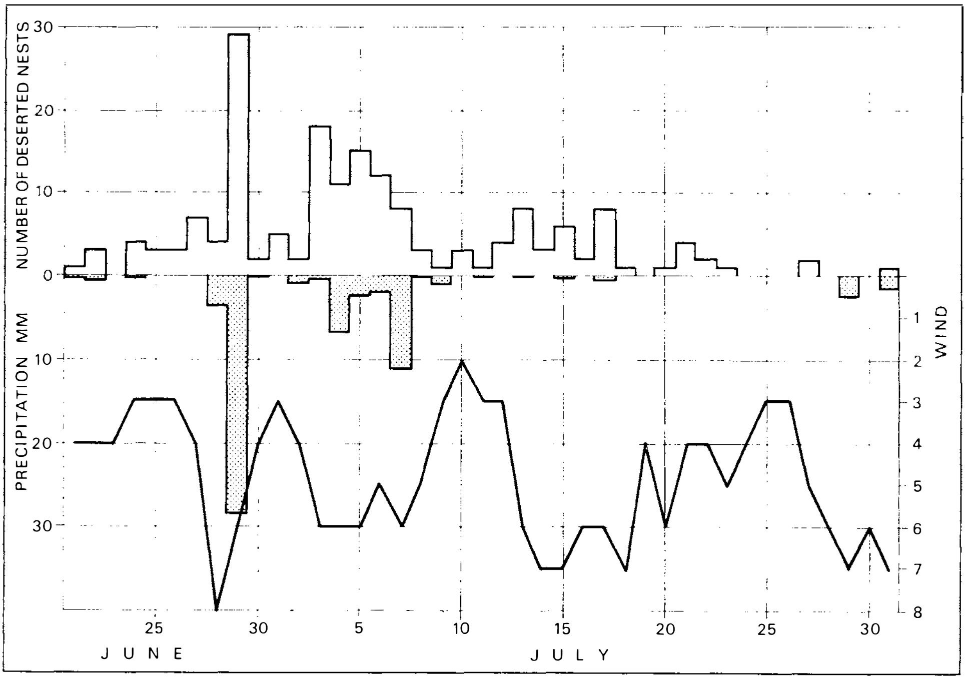


Fig. 4. *Relation between number of deserted nests (staples above), precipitation (staples below), and wind (Beaufort scale (curve)) in 1970.*

Отношение между числом покинутых гнезд (верхняя гистограмма), количеством осадков (нижняя гистограмма) и силой ветра (по шкале Бофорта (кривая)) в 1970 г.

Production potential of the colony

Table 4 shows the production potential in 1969 and 1970 in the number of young produced per nesting attempt and as a percentage of the total colony and of nests observed throughout the whole nesting phase.

In theory, it would be presumed that the number of full broods and the number of young leaving the nest are identical. In practice, however, a certain wastage in the number of eggs must be taken into account, some being infertile and others not hatched for some reason. It also occurs that a few newly-hatched chicks remain in the nest when the rest of the brood have left. Minimum wastage

Table 4

Production potential recorded 1969 and 1970

	Year	Fully-laid broods	Young leaving nest	Nesting success	Young per nesting attempt
Total	1969	4.46 (100%)	3.96 (88.8%)	69.9%	2.77 (62.1%)
Completed nesting	«	4.52 (100%)	4.11 (90.9%)	«	2.87 (63.5%)
Total	1970	4.47 (100%)	3.89 (87.0%)	52.0%	2.02 (45.2%)
Completed nesting	«	4.35 (100%)	3.85 (88.5%)	«	2.00 (46.0%)

of 5–10 % should therefore be considered realistic. If the percentage of successful nesting is put at 70 % (which is possible in a favourable year), the production potential will be around 63 %–66.5 %. An average number of 4–5 eggs for every full brood will give a theoretical production potential of 2.84–2.99 young for each nesting attempt.

Discussion

Average nesting success in the Kapp Linné colony (i.e. the number of successes of the total nesting attempts) was for both season taken together 65.5 % (52.0–69.9 %). In comparison, Milne (1963) found in Scotland that nesting success varied between 60 % and 68 %. Ahlén and Andersson (1970) found an average nesting success of 66 % in the Kongsfjord area of Spitsbergen, and also showed the highest rate of success in those parts of the population which nested in colonies together with the Arctic tern or in areas of high nest density (one nest for every square metre). Figs. 5 and 6 show that the influence of predators was little in the area around the radio station, increasing towards the outer fringes of the colony, which corresponds well to the fact that the area where the Arctic terns nested was concentrated around the radio station building. Where

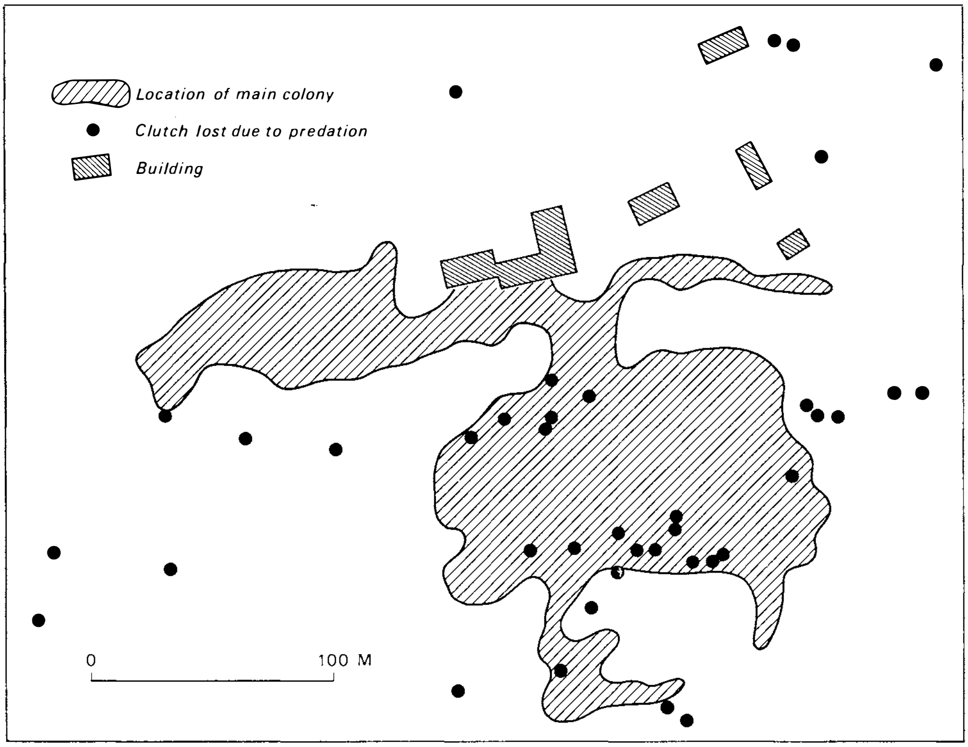


Fig. 5. *Location of main colony 1969 and distribution of clutches lost due to predation.*
Местонахождение основной колонии в 1969 г. и размещение по ней утраченных вследствие хищничества кладок.

BELOPOL'SKII (1961) states that the frequency of destroyed nests was 5 %–28 % at Novaja Zemlja and 3 %–18 % on the Murmansk coast, the protective measures used in these areas (predator control, construction of nesting sites, etc.) should be taken into account.

If the rate of nesting success for the two seasons is compared (Table 1), it is apparent that the difference (17.9 %) mostly lies in the fact that a greater number of nests were deserted in 1970 than in 1969. Taking into account that in 1969 the whole course of nesting was recorded while in 1970 the initial part of the egg-laying phase was not studied, the impressions of a poor 1970 season is further confirmed.

The material from the present studies points to a 70 % nesting success for the eider as the maximum to be expected in Svalbard. 1969 can moreover be considered as providing optimum productivity conditions. If nesting success is taken as the number of young produced compared to the total number of eggs produced (Table 2), the figures are then 67.4 % for 1969 and 45.0 % for 1970. This means that productivity in the individual nesting attempt varied far less than for the colony taken as a whole. Preliminary studies in 1968 showed an average brood size of 4.55 eggs (n = 275) (NORDERHAUG unpubl.). Material from 1969 and 1970 further confirms this (Tables 2 and 3), and the figure should be considered as approaching the maximum for the average brood size of the eider on Svalbard.

LØVENSKIOLD (op.cit.) believes that where there are more than 6 eggs in a brood, this is a result of stealing or that several females have laid eggs in the same nest. Experiences from Kapp Linné show some instances, if rare, of 9–10 eggs being laid by one and the same female at one and the same nesting attempt. Numbers in excess of this were nearly always the result of irregularities such as mentioned above. In extreme cases, up to 16 eggs were found in one nest, but such abnormally large broods were not, as far as could be observed, successful.

As is shown in Table 2, there is a marked difference in the average size of brood for all nesting attempts in the two seasons, the explanation of which being as follows: The material from 1969 included all nesting attempts interrupted before the brood was fully laid. In 1970, many of the cases where nesting was interrupted before observations began are not included in the results. The difference in the size of the fully-laid broods in the case of nestings observed in their entirety during the two seasons has another cause (Table 3). Late nesting attempts and double-brooding are over-represented in the 1970 material. According to LACK (1968) the brood size of ducks decreases the later egg-laying takes place (also when it is not a question of double-brooding). MILNE (op.cit.) too has found this in the case of the eider duck. These findings are contrary to PAYNTER'S (1951) assumptions that there is no significant difference in brood sizes in early and late nesting attempts for the eider.

One general factor which is obvious from the data obtained at Kapp Linné is that there is a certain wastage in the number of eggs during incubation, so that it is not always possible to reckon the number of eggs in a brood being incubated as a fully-laid brood. If we compare such a way of determining brood

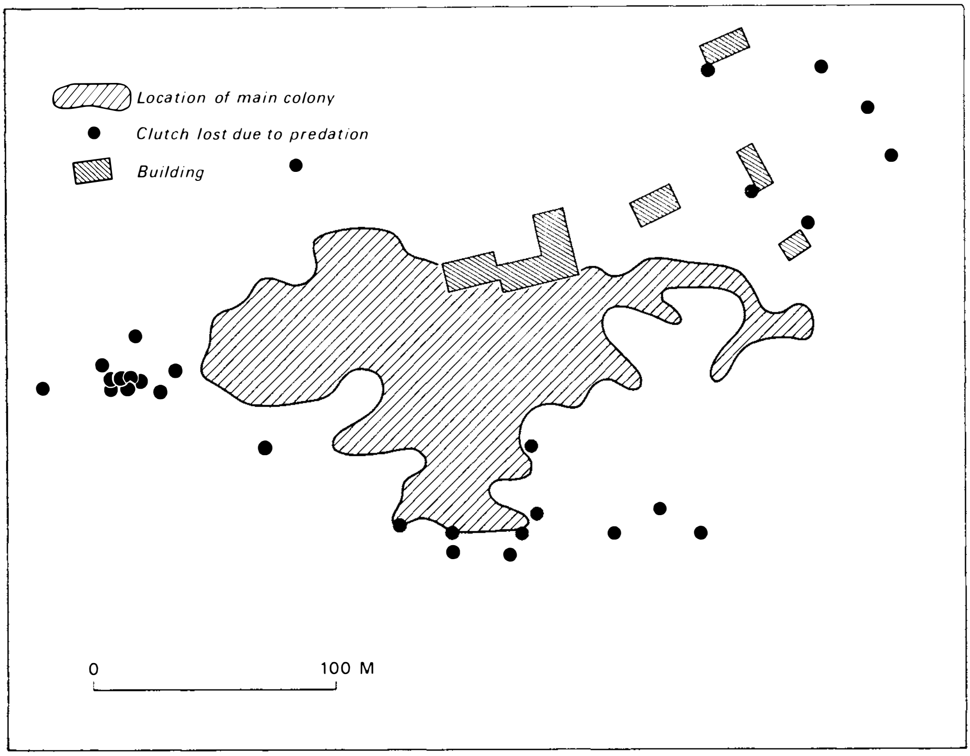


Fig. 6. *Location of main colony 1970 and distribution of clutches lost due to predation.*
Местонахождение основной колонии в 1970 г. и размещение по ней утраченных вследствие хищничества кладок.

size (Fig. 1) with the figures for fully-laid broods and brood size at the commencement of hatching (Tables 2 and 3), it is obvious that the method does not give a clear picture unless we know when in the nesting process the recording is made and how synchronized the process is in other seasons forming the basis for comparison. If we look at the average wastage during nesting (the difference between average size of fully-laid brood and average number of young leaving the nest), the figure was 0.50–0.58 eggs per brood, all background material taken into account (Table 2) A more correct picture of wastage is obtained by using only the results of nestings observed throughout the whole nesting process (Table 3), when the figures were 0.40–0.41 eggs per brood (9.13%). Similar observations made show great divergencies. In three colonies in Sweden, egg wastage varied from 2–3 % up to 18 %, dependent on the threat from predators (AHLÉN and ANDERSSON op. cit.), while MILNE (op. cit.) found in Scotland a 5 %–8 % wastage. COOCH (1965) reports an 18.2 % wastage in Arctic Canada, mainly due to predators. Even under optimum conditions, wastage as concerns Svalbard should be put at 10 %.

Concerning at what stage in the nesting process egg wastage is greatest, it can be seen that wastage during incubation averaged 0.17 eggs per brood (0.15–0.18) or 3.72 %, while in the hatching phase the average was 0.24 eggs per brood

(0.23–0.25) or 5.41 % (Table 3). In the Kongsfjord region AHLÉN and ANDERSSON (op. cit.) found that the average wastage during incubation was 0.54 eggs per brood (16.2 %). MILNE (op. cit.) found no appreciable difference in the size of fully-laid broods and broods at the beginning of hatching; wastage here took place in connection with hatching. This shows that wastage in the incubation phase in the Kapp Linné colony is low, which must be due to the small number of predators in the region.

Wastage in the hatching phase is difficult to determine where predators are of some account, as the latter will immediately seize any eggs remaining in the nest when the rest of the young have left. No special studies were made of wastage amongst juveniles after leaving the nest, but the general impression was that loss through predators in the Kapp Linné area was negligible in this phase. Cases of Glaucous gulls taking a young eider were seen only rarely. Findings from Kongsfjord area show the same tendency, while in other colonies in Svalbard the opposite was the case, loss through predators being greatest when the young eiders were on the sea (MILNE op. cit., AHLÉN and ANDERSSON op. cit.).

The studies show that the highest recorded production potential was 2.87 young per nesting attempt (63.5 %). In favourable nesting seasons an even higher figure may be reached, but it is unlikely to be as many as three young per nesting attempt, a figure which should be regarded only as a theoretical (and maximum) production potential both for the Kapp Linné colony and for Svalbard as a whole.

That so many of the nests were placed in the vicinity of the tern colony and near the main Isfjord Radio building should be considered as one of the most important factors contributing to the reduced threat from predators in this colony. The terns discourages preying by Glaucous gulls and Arctic skua while the Arctic fox was effectively kept away by the radio station personnel. At the same time, the number of good nesting places, both natural and artificial, contributed towards good nesting conditions in the area. All these factors combined provide favourable conditions for productivity. Unfavourable weather conditions is the only factor of importance which might reduce productivity during the nesting phase. That bad weather can influence productivity to a high degree and that different groups of birds can be affected to varying extents has been shown by several observers (i.a. JEHL Jr. and HUSSEL 1967, and SPJØTVOLL 1972).

The June and July temperatures in 1969 and 1970 at Kapp Linné showed only small variations from the normal, except for the late spring in 1969. However, during the same period in 1970 there was five times as much precipitation as in 1969. Furthermore, during the summer of 1970 there were strong winds, while relatively calm wind conditions applied in 1969 (HAGELUND and NORDERHAUG 1974, HAGELUND 1973). Fig. 4 shows that a combination of strong winds and precipitation coincides with times when the greatest number of nests were deserted. That such spells of bad weather took place while most of the females were incubating in 1970 must therefore be taken into account.

Weather conditions similar to those on 28 and 29 June 1970 also applied on 2 and 4 August 1969. However, at that time nearly the whole colony was deserted and effects on productivity were slight. It seems obvious that unfavourable conditions in the form of strong winds and high precipitation during the nesting process, and in particular during incubation, can lead to considerably reduced productivity in Svalbard, chiefly because the incubating females abandon the nesting attempt.

References

AHLÉN, I. and Å. ANDERSSON, 1970: Breeding Ecology of an Eider Population in Spitsbergen *Ornis Scand.* **1**. 83–106.

BELOPOL'SKII, L. O., 1961: *Ecology of the sea colony birds of the Barents Sea.* Jerusalem (IPST 125). 346 pp.

BURTON, P. J. K., N. G. BLURTON-JONES, and C. J. PENNYCUICK, 1960: Bird notes from Vest-Spitsbergen in the summer of 1957. *Sterna.* **4**. 113–140.

COOCH, F. G., 1965: The Breeding Biology and Management of the Northern Eider (*Somateria mollissima borealis*) in the Cape Dorset Area, Northwest Territories. *Can. Wildl. Service. Wildl. Mgmt. Bull.* **2** (10). 68 pp.

HAGELUND, K., 1973: Studier av ærfuglens (*Somateria mollissima* (L)) hekkebiologi på Svalbard. *Unpubl. Thesis. Univ. Oslo.* 71 pp.

HAGELUND, K. and M. NORDERHAUG, 1974: Studies of the population changes and breeding processes in a colony of Eiders (*Somateria mollissima* (L)) in Svalbard. *Norsk Polarinstitutt Årbok* 1973.

JEHL, J. R. jr. and D. J. T. HUSSEL, 1966: Effects of Weather on Reproductive Success of Birds at Churchill, Manitoba. *Arctic.* **19**. 185–191.

LØVENSKIOLD, H. L., 1963: Avifauna Svalbardensis. *Norsk Polarinstitutt Skrifter.* Nr. 129. 460 pp.

MILNE, H., 1963: Seasonal Distribution and Breeding Biology of the Eider (*Somateria mollissima* (L)) in the North-East of Scotland. *Unpubl. Ph. D. Thesis. Univ. Aberdeen.* 235 pp.

NORDERHAUG, M., 1968: Ornitologisk feltarbeid på Svalbard 1968. *Sterna.* **8**. 187–190.

— 1970: Ornitologisk feltarbeid på Svalbard 1969. *Sterna.* **9**. 107–109.

PAYNTER, R. A., 1951: Clutch size and egg mortality of Kent Island Eiders. *Ecology.* **32**. 497–507.

SPJØTVOLL, Ø., 1972: Ornitologiske observasjoner i forbindelse med et kraftig snevær i juni 1971. *Sterna.* **11**. 97–104.

Tetthet av hekkende vadere på tundraen omkring Ny-Ålesund, Svalbard

(Density of breeding waders on tundra around Ny-Ålesund, Svalbard)

AV SVEN-AXEL BENGTSON[1]

Innhold

Abstract

The number of broods of waders, within a defined plot (3.1 km^2) of coastal tundra around Ny-Ålesund, Kongsfjorden area, Svalbard (approx. 79°N, 12°E), was censused in the late summer using a mapping-method. Five breeding species were recorded: *Charadrius hiaticula*, *Calidris maritima*, *Crocethia alba*, *Arenaria interpres*, and *Phalaropus fulicarius* (Table 1). The total density was about 7 and 5 broods per km^2 in 1973 and 1967, respectively.

Innledning

En ekspedisjon fra Zoologisk museum ved Universitetet i Bergen drev i tidsrommet 3.—17. august 1973 markøkologiske undersøkelser omkring Ny-Ålesund og i Kongsfjordenområdet. Samtidig ble det også utført en del ornitologisk feltarbeid der det bl.a. ble gjort forsøk på å beregne antall hekkende vadere (antall adulte fugler med unger) innen et definert område omkring Ny-Ålesund (ca. 79°N, 12°E). En samtidig undersøkelse av fjæreplyttens, *Calidris maritima*, næringsøkologi vil det bli gjort rede for i en separat artikkel.

Observasjonene kompletteres med iakttakelser fra samme område i 1967, da jeg deltok i en ornitologisk ekspedisjon fra Lunds universitet.

[1] Zoologisk Museum, Universitetet i Bergen, 5014 Bergen/Univ.

Undersøkelsesområdet

Observasjonene ble konsentrert til et ca. 3.1 km^2 stort prøveareal omkring Ny-Ålesund (Fig. 1). Prøvearealet, bortsett fra selve Ny-Ålesund, består for det meste av kysttundra med et oftest temmelig sammenhengende vegetasjonsdekke dominert av lav (mest *Cetraria*-arter) og med innslag av *Salix polaris*, *Saxifraga oppositifolia*, *Silene acaulis*, *Dryas octopetala* og annen karakteristisk vegetasjon for tundraen. På høyereliggende mark, opp mot Zeppelinfjellet, finnes steinete polygonmark med sparsom vegetasjon. Et antall små bekker renner ned mot Zeppelinhamna, og omkring disse dannes ofte fuktige partier med rik mosevegetasjon. Langs stranden av Zeppelinhamna finnes partier med sand og små, grunne laguner. Inne i Ny-Ålesund, bakenfor havnen, ligger et større mosebevokst myrområde (i fortsettelsen kalt «myren») og i østre delen av samfunnet ligger en større og en mindre vannsamling («store hølen» og «lille hølen») der den førstnevnte tjener som kloakkutslipp og er omgitt av gytjeflater. En mindre del av prøvearealet opptas av selve bebyggelsen i Ny-Ålesund.

For en oversiktlig beskrivelse av Kongsfjordenområdet som helhet når det gjelder fuglefaunaen, henvises til AHLÉN & ANDERSSON (1970).

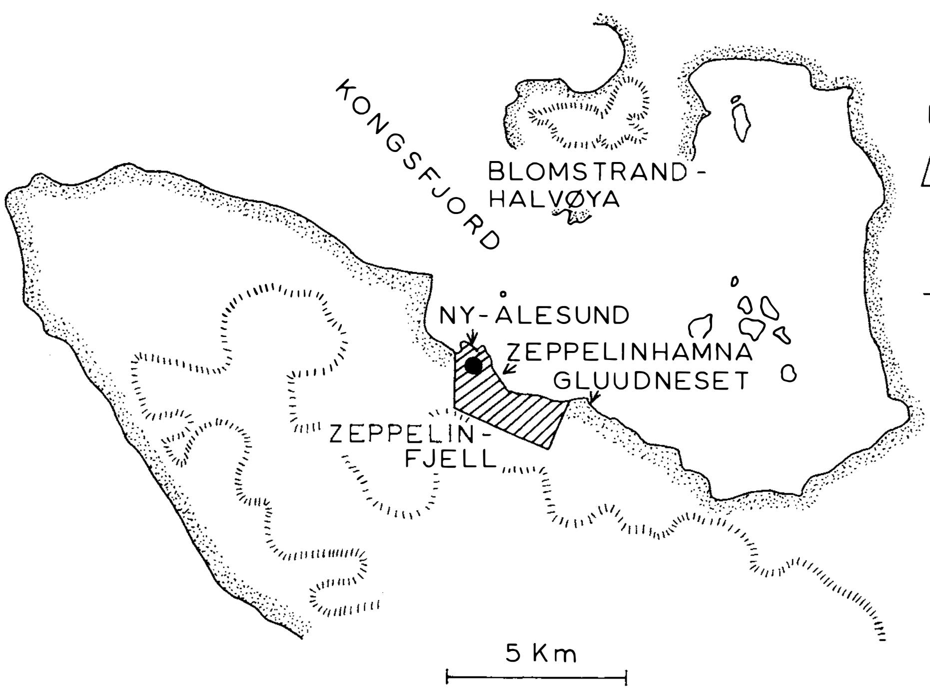


Fig. 1. *Kongsfjordenområdet med undersøkelsesområdet omkring Ny-Ålesund inntegnet.*
Kongsfjorden area with the census plot (hatched) around Ny-Ålesund.

Hekkende vadere

Antallet hekkende par av vadere innenfor prøvearealet ble beregnet utelukkende ut fra observasjoner av adulte fugler med unger. Observasjonene ble gjort i en periode da alle eggene var klekket eller ble klekket. Ved regelmessige ekskursjoner til alle deler av prøvearealet ble alle ungekull og adulte vadere plottet inn på et feltkart. Gjennom de adulte fuglenes oppførsel (varsellyd og avledningsoppførsel) var ungekullene som regel lette å finne (ikke alltid selve ungene, men ganske snart den plassen hvor de befant seg). Prøvearealet var ganske godt avgrenset fra de omliggende områdene ved hav, fjell, større bekker og store vegetasjonsfrie felt nedenfor breene øst for Ny-Ålesund. Områdene omkring var nesten helt tomme for fugl og noe utbytte av betydning av ungekull mellom prøvearealet og de omkringliggende områdene forekom derfor ikke.

Fem arter vadere ble funnet hekkende (Tabell 1): sandlo *Charadrius hiaticula*, fjæreplytt *Calidris maritima*, sandløper *Crocethia alba*, steinvender *Arenaria interpres* og polarsvømmesnipe *Phalaropus fulicarius*. Av disse var fjæreplytten den vanligste med 11 par (ungekull) fordelt på hele prøvearealet, men med flertallet på den steinete tundraen sør og sør-vest for Ny-Ålesund. De fem parene av sandlo fantes langs Zeppelinhamna (3 par) og sør for myren. Alle fire parene av polarsvømmesnipe hekket innenfor myren. Steinvenderparet hekket i tilknytning til den store hølen og sandløperparet ble påtruffet oppe på tundraen like vest for Gluudneset. Den siste arten har meg bekjent ikke tidligere vært funnet hekkende i Kongsfjordenområdet. Ett par av steinvender hekket på Blomstrandhalvøya 1956 og har tidligere hekket i Ny-Ålesund (LØVENSKIOLD 1964, s. 177, NORDERHAUG 1970, VOISIN 1970 og GULLESTAD 1973).

Totalt ble påtruffet 22 kull av vaderunger (ca. 7 pr. km^2) mot 15 eller 16 (ca. 5 pr. km^2) i samme tidsrom 1967 (Tabell 1). Ifølge mine inntrykk er tettheten av vadere noe høyere omkring Ny-Ålesund enn på andre lokaliteter.

Table 1.

Antall ungekull av vadere på tundramark omkring Ny-Ålesund, Kongsfjorden, Svalbard. Størrelsen på prøve-arealet var ca. 3.1 km^2 og feltarbeidet ble utført 3—17 august 1973 og i siste uke av juli og begynnelsen av august 1967. (Number and density of broods of waders on tundra around Ny-Ålesund, Svalbard. The size of study plot was 3.1 km^2).

Art (Species)	Antall ungekull (Number of broods) 1967	1973	Ungekull/km^2 (Broods/km^2) 1967	1973
Ch. hiaticula	3	5	1.0	1.6
C. maritima	8	11	2.6	3.6
C. alba	0	1	0	0.3
A. interpres	0	1	0	0.3
Ph. fulicarius	4—5	4	1.3—1.6	1.3
Totalt	15—16	22	4.8—5.2	7.1

Muligens kan dette tilskrives det faktum at området er godt beskyttet for predatorer (først og fremst fjellrev *Alopex lagopus*), gjennom menneskelige aktiviteter og tilstedeværelsen av mange og meget aggressive rødnebbterner *Sterna paradisaea*. Muligens bidrar også de gode næringsbetingelsene, som nærheten til havstranden, myren og hølene, til den høye tettheten. Det skal også understrekes at den ovenfor beregnede tettheten for hekkende vadere naturligvis er et minimumsiffer og at antall par som på forsesongen hevder revir og begynner hekking kan være betydelig større.

Takk

Deltakere i ekspedisjonen fra Zoologisk museum ved Universitetet i Bergen var foruten forfatteren også vit.ass. TORSTEIN SOLHØY og cand.mag. ARNE FJELLBERG. Feltarbeidet ble bekostet gjennom tilskudd fra Meltzers Høyskolefond, Universitetet i Bergen (gjennom professor HANS KAURI) samt av Zoologisk museum. Foruten all støtte fra professor HANS KAURI, styrer ved Zoologisk museum, vil jeg også nevne stasjonssjef KRISTIAN SNELTVEDT i Ny-Ålesund og Sysselmannen i Longyearbyen som begge sterkt bidro til den vellykkete gjennomføringen av ekspedisjonen. De supplerende opplysningene fra 1967 ble innsamlet under Lunds Universitets Svalbard Expedition 1967 (ledet av professor INGEMAR AHLÉN).

Litteratur

AHLÉN, I. and Å. ANDERSSON, 1970: Breeding ecology of an Eider population on Spitsbergen. *Ornis Scand.* **1**, 83–106.

GULLESTAD, N., 1973: Noen observasjoner av pattedyr og fugl i Kongsfjordområdet, Spitsbergen, 1970–1971. *Norsk Polarinstitutt Årbok* 1971. 59–66.

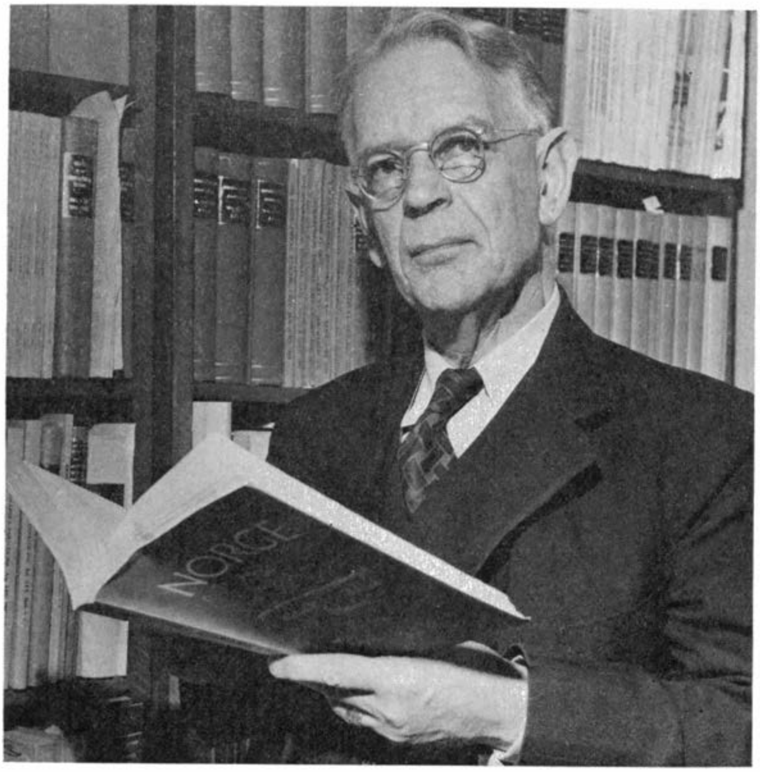
LØVENSKIOLD, H. L., 1964: Avifauna Svalbardensis. *Norsk Polarinstitutt Skrifter* Nr. 129, 1–460.

NORDERHAUG, M., 1970: Dyrelivet på Svalbard i 1968. *Norsk Polarinstitutt Årbok* 1968, 101–106

VOISIN, J.-F., 1970: Some notes about birds and mammals in Svalbard, summer 1969. *Ibid.* 1969, 105–115.

Hans W:son Ahlmann

AV OLAV LIESTØL



Professor og ambassadør HANS W:SON AHLMANN døde 11. mars 1974 i Stockholm i en alder av 85 år.

AHLMANN var geograf og studerte i sin ungdom morfologi. Hans hovedarbeid var landskapsformene i Norge, spesielt utviklingen av daler og dalgenerasjoner. Bre-erosjonens rolle som en av de viktigste agenser i utformingen av landet fikk ham til å interessere seg spesielt for deres oppførsel, ikke bare for den formskapende evne, men etter hvert også for deres reaksjoner på klimatiske faktorer. Uten i grunnen selv å være geofysiker, satte han i gang undersøkelser av Styggbreen i Jotunheimen. Det var gjort mye glasiologi før ham, men det var helst studier av breens bevegelser og målinger av bretungenes fram- og tilbakerykking som tidligere hadde vakt forskernes interesse. Han var den første som studerte den samlede volumvariasjon på en bre og dennes sammenheng med de klimatiske faktorer. Dette førte ham videre til studier av breer i forskjellige klimatiske miljøer og i årene fremover til annen verdenskrig organiserte og deltok han i en rekke ekspedisjoner omkring det nordlige Atlanterhav.

Han hadde alltid med seg fremragende eksperter innenfor de forskjellige faggrener. Mange av de undersøkelser som ble foretatt er blitt stående som klassiske og det er stadig blitt henvist til dem i faglitteraturen. Av ekspedisjonene kan man nevne den svensk-norske ekspedisjon til Nordaustlandet i 1931, den norsk-svenske ekspedisjon til Spitsbergen i 1934 hvor blant andre H. U. SVERDRUP var med, den svensk-islandske ekspedisjon til Vatnajökul i 1936 og den svenske ekspedisjon til Nordøst-Grønland i 1939.

Under krigen fikk han anledning til videre å analysere sine resultater og ble mer og mer interessert i breenes reaksjon på de klimatiske fluktuasjoner. Han organiserte den årlige undersøkelsen av massebalansen på Storglacieren som siden er blitt et mønster og er den lengste sammenhengende serie av slike undersøkelser som er foretatt.

Gjennom sin omfattende erfaring har Ahlmann kunnet gi perspektiver til beskrivelsen av de markerte og storstilte klimatiske variasjoner som har satt spor etter seg på så mange vis i historisk tid. AHLMANN utvidet også sine studier til å gjelde de globale forandringer i klimaet og de forandringer miljøet på jorden derved blir utsatt for. Det siste store prosjekt som han var med og organiserte, den norsk-britisk-svenske Antarktisekspedisjon 1949—52, er kanskje et resultat av hans forståelse av de klimatiske variasjoners globale sammenheng.

AHLMANN var ikke bare vitenskapsmann, hans administrative evner og omfattende interesser satte spor etter seg på så mange områder. Utenom hans store glasiologiske og klimatologiske forfatterskap, kan nevnes almengeografiske bøker som «Norge, natur och näringsliv» og «Nutida Sverige», og dessuten var han hovedredaktør og medforfatter i «Allmän Världsgeografi». Han hadde også en rekke administrative hverv, blant annet var han president i Den internasjonale geografiske union i årene 1956—60.

Gjennom sitt giftermål og sin forskning var han spesielt knyttet til Norge. Dette kom til uttrykk i hans omfattende hjelpearbeid under og etter krigen og i hans arbeid som svensk ambassadør i Norge i årene 1950—56.

Glaciological work in 1973

(Гляциологические работы в 1973 г.)

By OLAV LIESTØL

Contents

Abstract

In 1973 mass balance studies were carried out on four glaciers in Norway, Storbreen, Hardangerjøkulen, Supphellebreen, and Blomsterskardbreen. In Spitsbergen mass balance was carried out on two glaciers, Austre Brøggerbreen, and Midre Lovénbreen. At Austre Brøggerbreen a glacihydrological program was also started with measurement of water discharge, sediment load, and different chemical components.

Length fluctuations ot eleven glacier tongues were measured; eight were retreating and three stationary.

Аннотация

Под наблюдением Норвежского Полярного Института (Norsk Polarinstitutt) в 1973 г. был исследован вещественный баланс четырех ледников в Норвегии (Storbreen, Hardangerjøkulen, Supphellebreen, Blomsterskardbreen) и двух ледников на Шпицбергене (Austre Brøggerbreen, Midre Lovénbreen). Начаты были работы по гляцпогидрологической программе комплексных исследований ледника Austre Brøggerbreen, включающей измерения количества водного стока, количества в нем осадочной нагрузки и количества входящих в нее различных химических составных частей.

Приводятся результаты измерений колебаний длины одиннадцати ледниковых языков, из которых отступили восемь, а три оказались стационарными.

Storbreen in Jotunheimen

In most of the accumulation period precipitation came with winds from the west. The increase in accumulation from east to west was therefore much larger than normal (diagram Fig. 9). The most westerly and maritime glacier, Ålfotbreen, has c. 50% higher accumulation, whereas Gråsubreen, the most

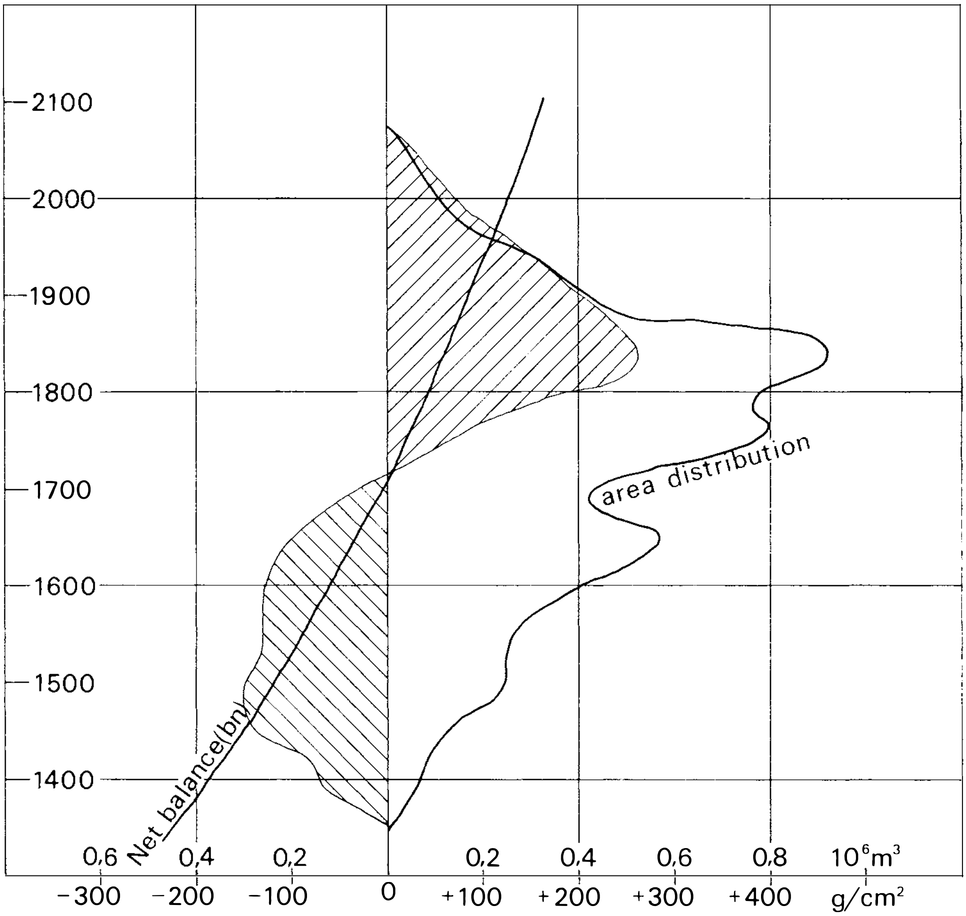


Fig. 1. *Variations in mass balance of Storbreen 1972–73 in relation to height above sea level.* Вариации вещественного баланса ледника Storbreen в 1972/73 г. в зависимости от высоты над уровнем м ря.

continental one of the measured glaciers, has c. 10% lower accumulation than normal. Storbreen is located almost on the watershed between east and west, but the precipitation comes mainly from the west. The accumulation was therefore above normal. The temperature was higher than average in the first half of the summer, but heavy snowfalls in the middle of August resulted in a less than average ablation during the rest of the summer. The result was a small positive balance, 8 g/cm² (Fig. 1).

The diagram in Fig. 2 shows the mass balance of Storbreen in the 25 years since measurements started in 1949. Ten years had a positive balance and fifteen years a negative one. Most of the positive figures are small, three of them in fact within the borders of uncertainty. The result is a large shrinking of the glacier. The average loss for the whole glacier is 746 g/cm², corresponding to c. 8.3 m of ice. Four years within the same period had a loss of more than 100 g/cm², the largest being that of 1968–69, when 142 g/cm² was lost.

Table 1.
Mass balance on Storbreen from 1948/49 to 1972/73

Year	Accumulation g/cm²	Ablation g/cm²	Net balance g/cm²
1948–49	228	208	+ 20
49–50	152	181	÷ 29
50–51	113	167	÷ 54
51–52	144	113	+ 31
52–53	140	225	÷ 85
53–54	121	198	÷ 77
54–55	157	206	÷ 49
55–56	131	148	÷ 17
56–57	142	137	+ 5
57–58	154	162	÷ 8
58–59	107	235	÷128
59–60	98	207	÷109
60–61	110	162	÷ 52
61–62	154	82	+ 72
62–63	96	214	÷118
63–64	116	95	+ 21
64–65	154	120	+ 34
65–66	125	186	÷ 61
66–67	189	117	+ 72
67–68	159	154	+ 5
68–69	122	264	÷142
69–70	97	169	÷ 72
70–71	143	128	+ 18
71–72	139	170	÷ 31
72–73	148	140	+ 8
Mean 1949–73	137,6	167,5	÷ 29,8

Table 1 and Fig. 3 show that the total volume increased in the period between 1963 and 1968. This was also observed by the triangulation of the stakes in the same years. The thickening was located only to the upper half of the glacier, and the increase could not produce a cinematic wave large enough to reach the terminus. In the summer of 1968 the southernmost small rock outcrop visible since 1955 disappeared, but reappeared two years later.

The glacier tongue has been in steady retreat since 1928, when the last push moraine was formed. As the height of the upper part of the glacier has been almost constant or has even increased in periods, the loss is concentrated to the lower part. In 1970 a rock outcrop appeared c. 200 m above the terminus, and the ice below this rock is now practically dead.

The diagram in Fig. 2 shows that the yearly variation in ablation is larger than the variation in accumulation. The standard deviation of the ablation is 43.5 g/cm² and 29.1 g/cm² for the accumulation. The ablation is dependent mainly upon radiation, convection, and condensation. The two last factors are again to a large extent dependent upon temperature. A good correlation be-

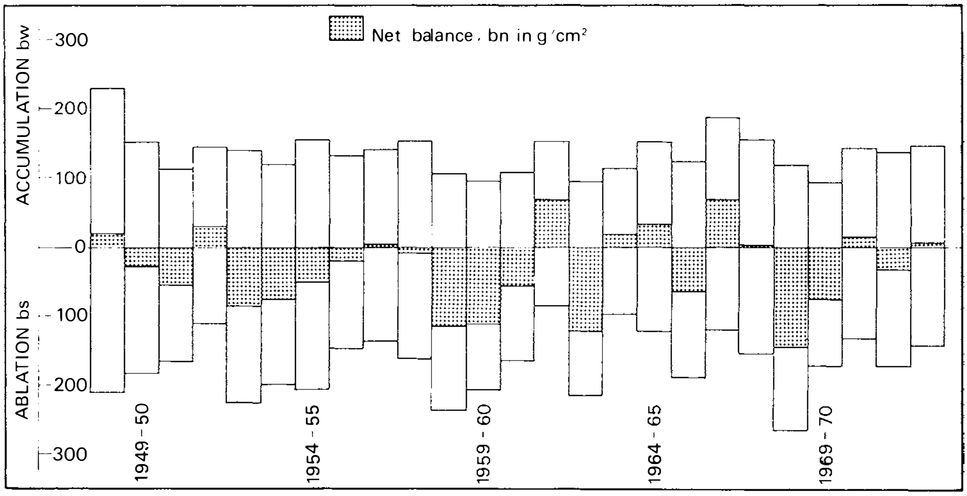


Fig. 2. *Variations in mass balance of Storbreen in the 25 years since measurements were started in 1948–49. Shaded areas represent net balance.*
Вариации вещественного баланса ледника Storbreen за 25 лет, прошедших с начала ежегодных измерений его в 1948/49 г. Пунктиром обозначен чистый баланс.

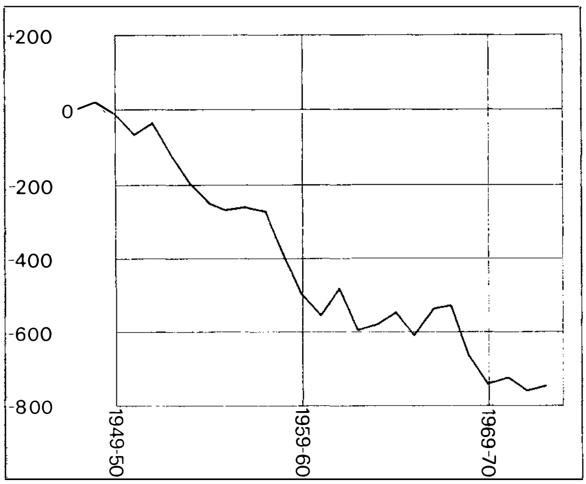


Fig. 3. *Cumulative net balance of Storbreen 1949–1973 in g/cm².*
Совокупный чистый баланс ледника Storbreen за 1949–1973 гг. в г/см².

tween radiation and temperature has also been observed. Therefore, there is good reason to believe that a good relation exists between ablation and temperature. This is a well-known fact and has also been observed directly on Storbreen (LIESTØL 1964). The conclusion is that variation in summer temperature is the main controlling factor for the yearly mass balance variation on Storbreen. In a more maritime climate variation in accumulation is a more decisive factor, as the absolute variation in precipitation is larger, and the variation in temperature is nearly the same.

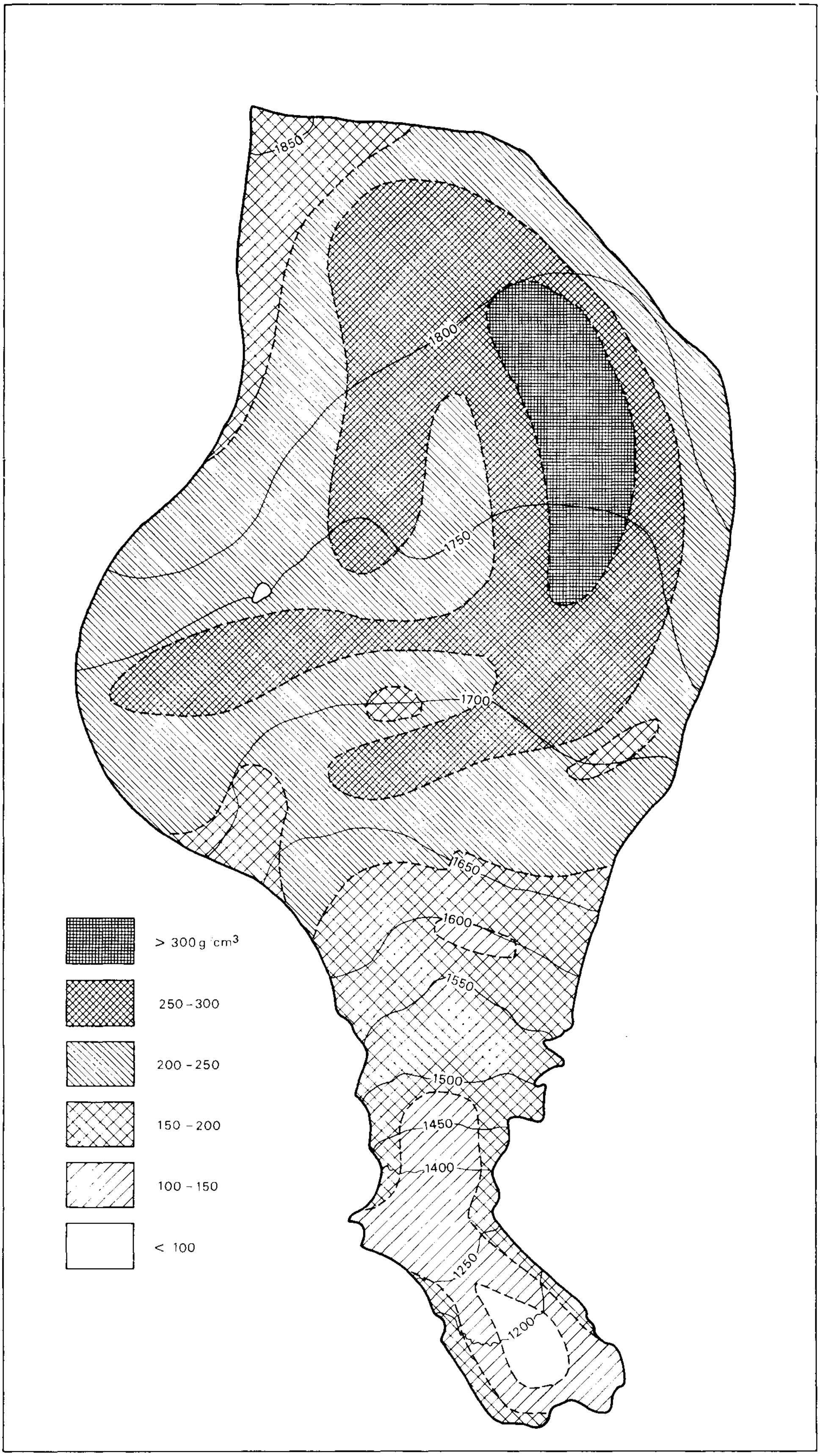


Fig. 4. *Distribution of snow accumulation in the part of Hardangerjøkulen which flows to the outlet glacier Rembesdalsskåki.*

Распределение снегонакопления в текущей на выводной ледник Rembesdalsskåki части ледника Hardangerjøkulen.

Hardangerjøkulen

When accumulation was measured in the beginning of May, only two of the stakes were visible above the snow. New stakes were placed where the buried stakes would emerge later in the summer, and core drilling was made to check snow depth and density. Hard crusts and large snow depth made ordinary soundings difficult. As on all glaciers in West Norway, accumulation was above normal and relatively higher than on Storbreen. For the first time it was even higher than that on Nigardsbreen. Ablation was also above average, 179 g/cm², but owing to the large accumulation, 262 g/cm², which is c. 50% above average, the result was a positive balance of 83 g/cm² (Table 2 and Figs. 3 and 4).

Table 2.
Hardangerjøkulen 1972–73

Height interval m a.s.l.	Area km²	Winter balance 10^6 m³	g/cm²	Summer balance 10^6 m³	g/cm²	Net balance 10^6 m³	g/cm²
1850–1900	0,070	142	200	78	÷112	64	88
1800–1850	3,375	8775	260	3983	÷118	4792	142
1750–1800	3,866	11404	295	5142	÷133	6262	162
1700–1750	3,910	11456	293	5826	÷149	5630	144
1650–1700	2,084	5731	275	3605	÷173	2126	102
1600–1650	0,936	2358	252	1797	÷192	561	60
1550–1600	0,640	1459	228	1389	217	70	11
1500–1550	0,542	1165	215	1328	÷245	— 163	÷ 30
1450–1500	0,319	606	190	887	÷278	— 281	÷ 88
1400–1450	0,196	327	167	615	÷314	— 288	÷147
1350–1400	0,112	172	154	429	÷352	— 257	÷198
1300–1350	0,084	123	147	329	÷392	— 206	÷245
1250–1300	0,270	389	144	1234	÷457	— 845	÷313
1200–1250	0,315	410	130	1581	÷502	— 1171	÷372
1150–1200	0,321	404	126	1749	÷545	— 1345	÷419
1100–1150	0,115	140	122	678	÷590	— 538	÷468
1050–1100	0,022	26	120	140	÷635	— 114	÷515
1070–1863	17,18	+45087	262	÷30790	179	14297	+ 83

Supphellebreen

Mass balance measurements were renewed at Supphellebreen, which previously had been studied from 1963 to 1968. For the 1972–73 balance year the net balance was determined to be approximately 150 g/cm².

Blomsterskardbreen, Folgefonni

The measurement on Blomsterskardbreen, an outlet glacier from the southern part of Folgefonni, was based only upon three stakes. However, the even and simple accumulation pattern registered in earlier years gives a reliable basis for

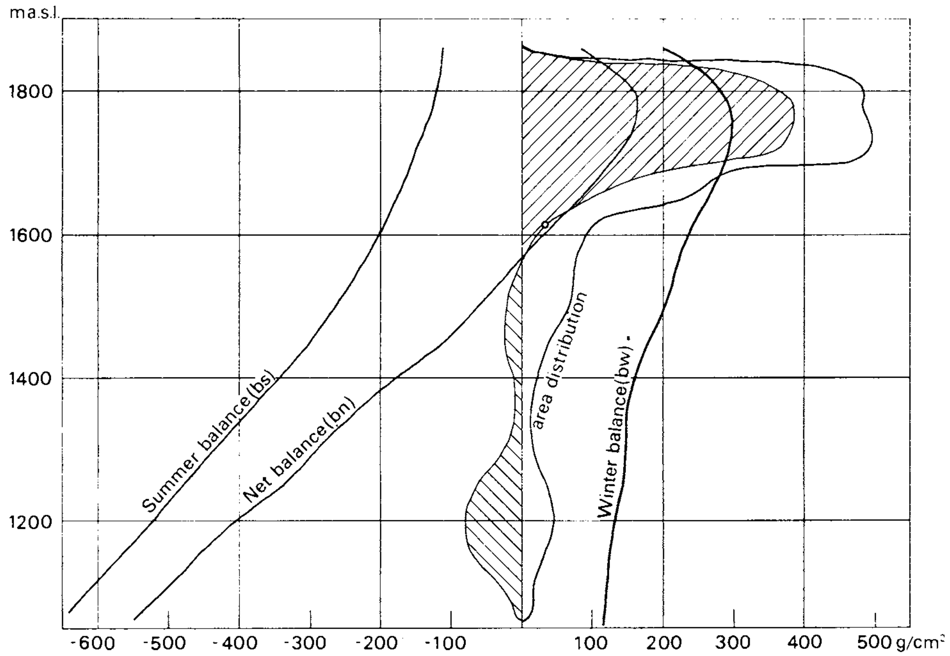


Fig. 5. *Variations in mass balance of Hardangerjøkulen (Rembesdalsskåki) 1972–73 in relation to height above sea level.*

Вариации вещественного баланса ледника Hardangerjøkulen (Rembesdalsskåki) в 1972/73 г. в зависимости от высоты над уровнем моря.

calculation of the mass balance. As no accumulation measurement has been made, only net balance figures are available.

The result of the calculation was a large positive balance of 157 g/cm².

Glaciers in Spitsbergen

In Spitsbergen mass balance studies were carried out on Midre Lovénbreen and Austre Brøggerbreen. BJØRN WOLD, who spent the winter in Ny-Ålesund, made detailed investigations to measure and calculate the superimposed ice on

Table 3.

Mass balance figures in g/cm² for Austre Brøggerbreen and Midre Lovénbreen 1967–73

Year	Austre Brøggerbreen			Midre Lovénbreen		
	$\bar{c}$	$\bar{a}$	$\bar{b}$	$\bar{c}$	$\bar{a}$	$\bar{b}$
1967	77	142	÷65			
1968	57	67	÷10	48	51	÷ 3
1969	40	133	÷93	41	125	÷84
1970	37	91	÷54	36	89	÷53
1971	65	123	÷58	70	116	÷46
1972	95	126	÷31	88	120	÷22
1973	74	82	÷ 8	82	84	÷ 2

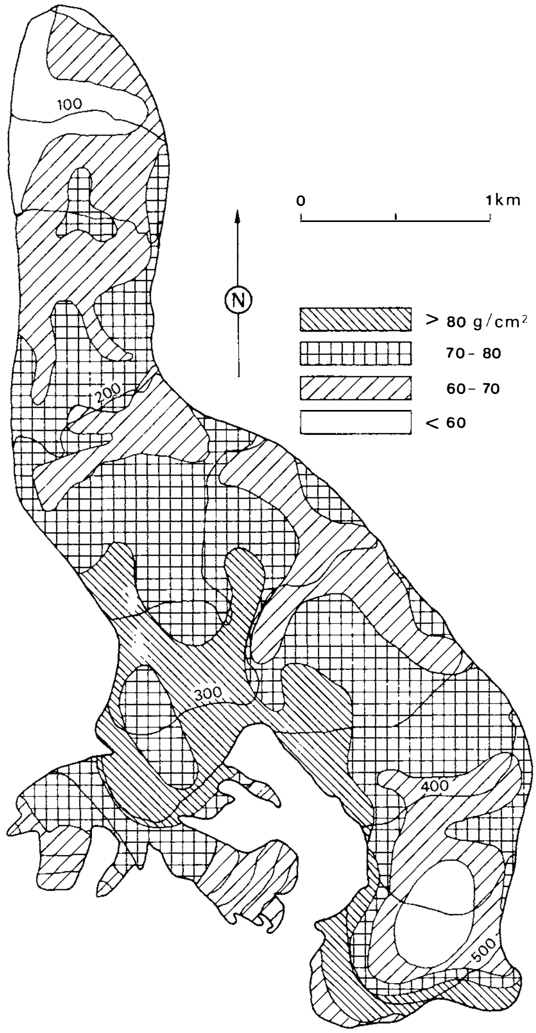


Fig. 6a. *Distribution of snow accumulation of Austre Brøggerbreen 1972–73.*
Распределение снегонакопления ледника Austre Brøggerbreen в 1972/73 г.

the two glaciers. In the accumulation area where snow remains, superimposed ice is formed during the whole ablation period. On the lower part of the glacier this is formed in two periods: during spring until the snow cover disappears, and in the autumn when rain and melt water in periods are soaking the first new snow covers. In the mass balance year of 1972–73, the superimposed ice formed during the autumn was 11 g/cm² and ice formed during spring and summer was 15 g/cm². The average total amount of superimposed ice is thus 26 g/cm² over the whole glacier. This means that 35% of the winter balance is superimposed ice (Fig. 8).

The autumn of 1972 was dry and the major part of the accumulation took place in the beginning of 1973. The total winter balance was 74 g/cm² for Brøggerbreen and 82 g/cm² for Lovénbreen, which is a little above the normal for the seven years of measurements. The ablation was 82 g/cm² and 84 g/cm², which is below the seven year average. Nevertheless the balance was negative

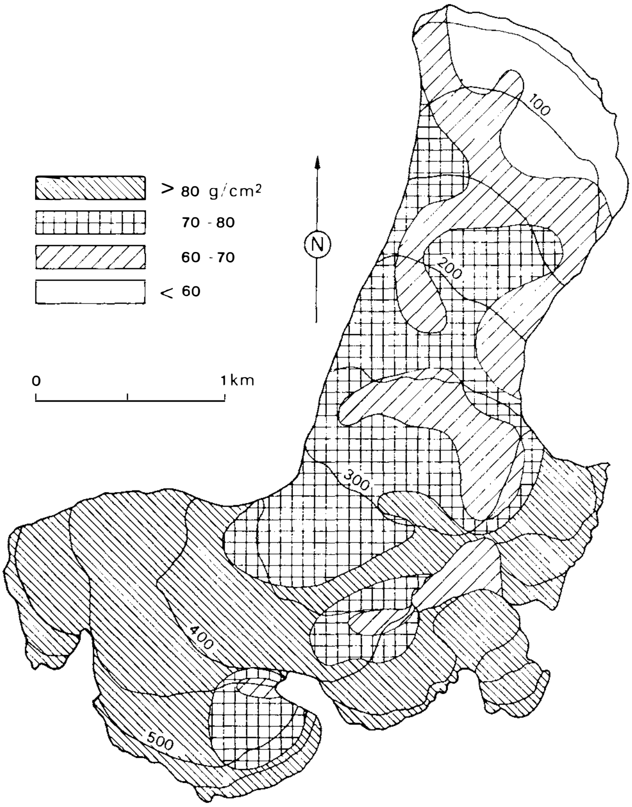


Fig. 6b. *Distribution of snow accumulation of Midre Lovénbreen 1972–73.*
Распределение снегонакопления ледника Midre Lovénbreen в 1972/73 г.

Table 4.
Mass balance measurements of different glaciers in Norway and Spitsbergen 1972–73

Name of Glacier	Area km²	Winter balance 10⁶ m³	Winter balance m	Summer balance 10⁶ m³	Summer balance m	Net balance 10⁶ m³	Net balance m
South Norway							
Ålfotbreen	4,79	22,36	4,67	11,91	2,49	10,45	2,18
Blomsterskardbreen	45,72					71,65	1,57
Nigardsbreen	46,56	112,07	2,40	60,47	1,30	51,60	1,10
Hardangerjøkulen	17,53	48,03	2,75	35,22	2,01	12,81	0,76
Storbreen	5,36	7,93	1,48	7,50	1,40	0,43	0,08
Hellstugubreen	3,30	3,96	1,20	4,67	1,41	÷0,73	÷0,21
Gråsubreen	2,53	1,82	0,72	4,06	1,61	÷2,24	÷0,89
North Norway							
Engabreen	38,02	166,10	4,37	62,73	1,65	103,37	2,72
Høgstuvbreen	2,58	10,09	3,90	7,27	2,82	2,82	1,08
Trollbergdalsbreen	1,82	5,80	3,19	4,43	2,43	1,37	0,76
Spitsbergen							
Brøggerbreen	6,12	4,53	0,74	5,01	0,82	÷0,48	÷0,08
Lovénbreen	5,87	4,81	0,82	4,92	0,84	÷0,11	÷0,02

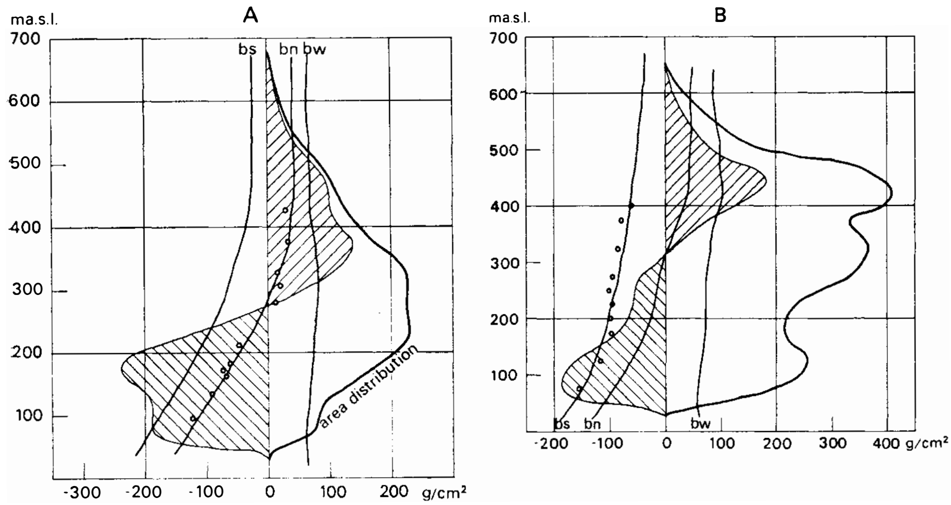


Fig. 7. *Variations in mass balance in relation to height above sea level of Austre Brøggerbreen (A) and Midre Lovénbreen (B) 1972–73.*

Вариации вещественного баланса ледников Austre Brøggerbreen (A) и Midre Lovénbreen (B) в 1972/73 г. в зависимости от высоты над уровнем моря.

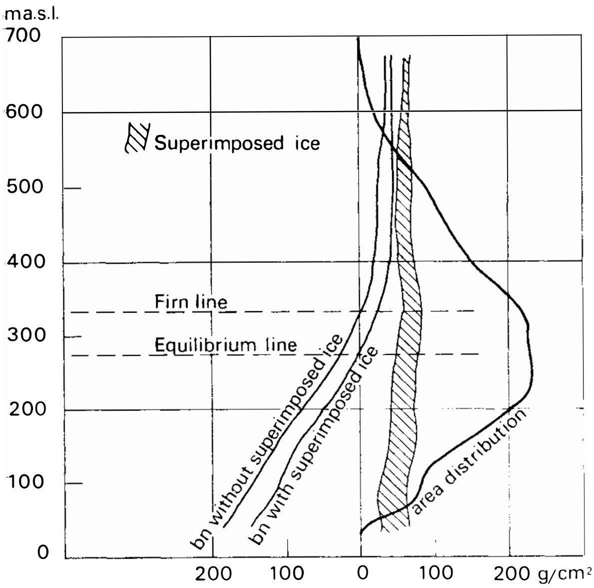


Fig. 8. *Variations in mass balance in relation to height above sea level of Austre Brøggerbreen with and without superimposed ice. The difference between firn line and equilibrium line is also shown.*

Вариации вещественного баланса ледника Austre Brøggerbreen в зависимости от высоты над уровнем моря с наложенным льдом и без него. Также показана разница между фирновой линией и линией равновесия.

because all the seven previous years had a negative balance. As we have no reliable data for the climate of the area, it is impossible to tell whether this is due to a lower accumulation or a higher temperature than normal. In Table 3 mass balance figures for the seven years are listed. For Brøggerbreen the total loss for the seven years is 319 g/cm² averaged over the whole glacier. As the velocity is low, only 2.5 m per year in the middle of the glacier, the transportation from the upper part to the tongue is far too little to compensate for the larger ablation in the lower part of the glacier. The result is a steady growing inclination of the ice surface. This is the case for almost all glaciers in Spitsbergen. When the gradient reaches a certain value this growing steepness will be succeeded by a surge. It is known when Brøggerbreen had its last surge, but photos from 1909 should indicate that it might have been around 1900.

Other investigations

The Norwegian Water Resources and Electricity Board carried out measurements on seven glaciers in Norway of which three, Engabreen, Trollbergdalsbreen, and Høgtuvbreen, are situated in northern Norway. These measurements

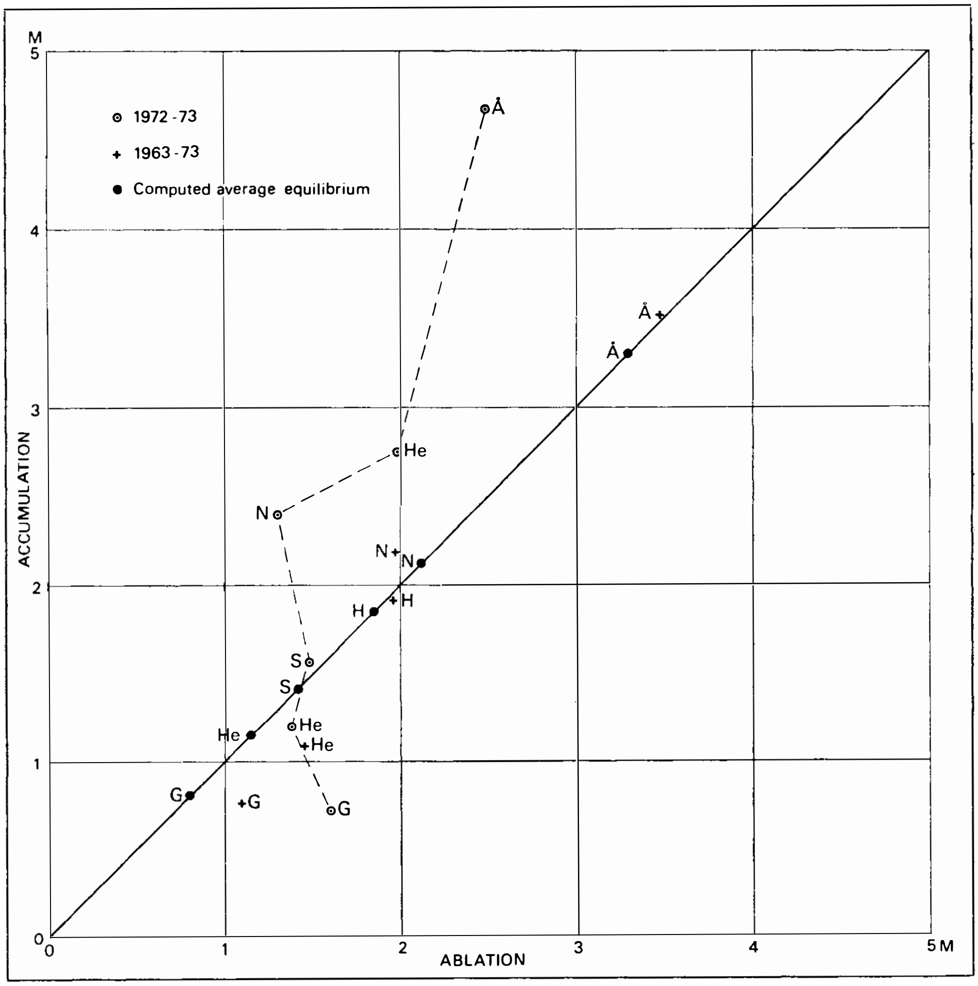


Fig. 9. *Relation between accumulation and ablation compared to the mean of the previous eleven years, and also to that of a year with a computed balance budget and a "normal" mass exchange.*
G = Gråsubreen. H = Hardangerjøkulen. He = Hellstugubreen. N = Nigardsbreen. S = Storbreen. Å = Ålfotbreen.

Взаимоотношения между аккумуляцией и абляцией в сравнении с средними значениями предыдущих одиннадцати лет, так же как с значениями года с подсчитанным балансированным бюджетом и ,,нормальным" вещественным обменом.

together with the investigations dealt with in this paper are presented in Table 4.

The mass balance figures for southern Norway are also presented graphically in Fig. 9. As in the two previous years, and even more pronounced, the western and more maritime glaciers have a higher positive balance than the eastern and more continental glaciers.

Measurements of the fluctuation of glacier tongues were carried out on a total of 11 glaciers, and the results are presented in Table 5.

Table 5.
Fluctuations in m of some glacier tongues

Jotunheimen			*Folgefonni*		
	Storbreen	— 5		Buarbreen	0
	Styggedalsbreen	0		Bondhusbreen	— 5
Jostedalsbreen			*Møre*		
	Briksdalsbreen	— 15		Trollkyrkjebreen	— 1
	Fåbergstølbreen	— 30		Finnebreen	0
	Stegaholtbreen	— 26	*Svartisen*		
	Austerdalsbreen	— 7		Engabreen	— 12

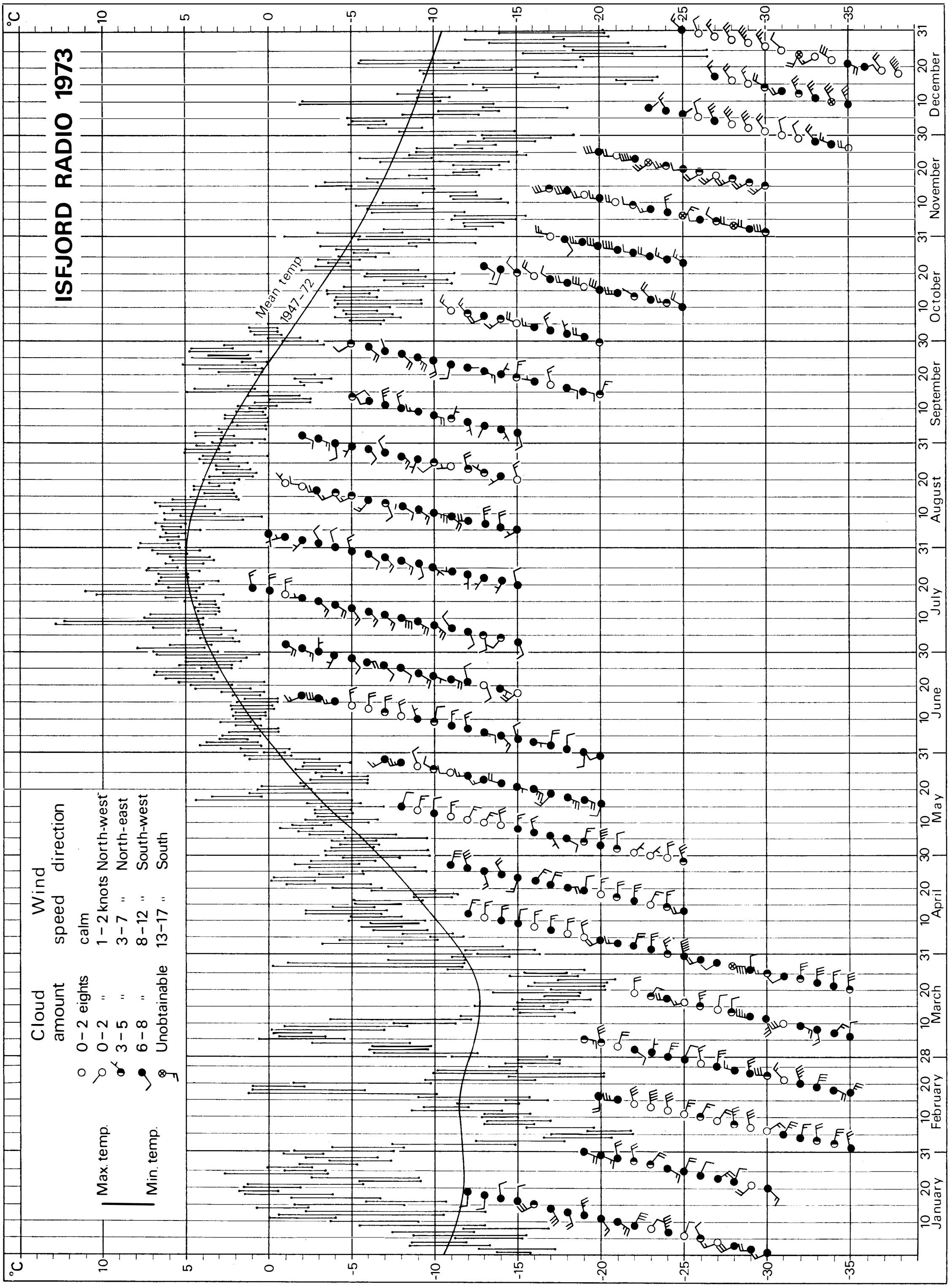
The weather in Svalbard in 1973

By Vidar Hisdal

The diagram presents some important meteorological elements observed at Isfjord Radio during 1973: the daily maximum and minimum temperatures, the cloud amount, and the direction and speed of the wind. The cloud and wind observations entered are those taken at 12 GMT. The figure also shows the average annual temperature variation for the period 1947–72. The symbols used are explained by examples in the diagram.

The table contains the monthly mean temperatures for Isfjord Radio, Hopen, and Bjørnøya for 1973 as well as their deviations from the means based on the period 1947–72. The term "normal" used below refers to this latter period.

The weather during the first week of January was dominated by a northerly air stream, with temperatures somewhat below or about the normal for the season, while the rest of the month was characterized by a cyclonic weather type. Several depressions passed the area and brought mild air from lower latitudes. Thus, at Isfjord Radio the period from 11 to 26 January had eight days in all with maximum temperatures equal to or higher than 0 °C. Apart from a very mild spell between the 17th and the 20th, most of February was cold, the air circulation being governed by a high pressure ridge over Greenland and cyclones moving in lower latitudes. The weather during the first days of March was influenced by mild air streams in connection with vigorous depressions approaching from the southwest. About 12 March, however, the temperature dropped considerably, as Arctic air entered between high pressure areas to the west and low pressure systems that became quasi-stationary in the Barents Sea and adjacent areas. A couple of days towards the end of the month had again a milder, cyclonic weather type. In April the winds were predominantly easterly, the depression centres passing generally to the south of the Svalbard archipelago. The air currents, however, were not of polar origin, but formed the continuation of a southerly stream in front of the depressions. A weak to moderate easterly current prevailed during the first half of May as well, with temperatures near or somewhat above the average. A cyclonic passage about the middle of the month gave a short, considerably milder spell. The weather during the last part of the month was dominated by a cool northerly air flow in the rear of a persistent low pressure system over the Kara Sea and neighbouring regions. The first week of June was characterized by a series of cyclonic passages, and somewhat above normal temperatures. The


ISFJORD RADIO 1973
Mean temp. 1947–72
°C
10
5
0
-5
-10
-15
-20
-25
-30
-35
Cloud amount
○ 0–2 eights
0–2
3–5
6–8
Unobtainable
Wind speed
calm
1–2 knots
3–7
8–12
13–17
Wind direction
North-west
North-east
South-west
South
Max. temp.
Min. temp.
January
February
March
April
May
June
July
August
September
October
November
December

cyclones then took a more southerly course, and an anticyclone built up over Greenland and the Canadian archipelago, resulting in transport of cool air from the Polar Basin over the Svalbard area. At about 20 June milder air from the south again invaded the islands, and several cyclonic passages took place during the last week of the month. A cyclonic weather type was dominating during the larger part of July and August as well, with comparatively mild air streams in the front of the cyclones, cooler air in the rear. The highest temperature of the year at Isfjord Radio, 12.7 °C, was observed on 8 July, in connection with advection of warm, continental air from the south. The first half of September was cool, and the air circulation was to a large extent governed by a high pressure area over Greenland and, later, over the Polar Basin. During the last half of the month, several depressions passed the area, and on the whole the temperature was appreciably above the long-term average. The larger part of October, and especially of November and December, was considerably colder than normal. The typical situation during this period was distinguished by a northerly, cold and partly strong air current between an anticyclone over Greenland or adjacent areas, and low pressure centres moving towards the northeast in lower latitudes. This general situation, however, was several times interrupted by short, milder spells, when cyclones passed over or near the islands and brought mild, maritime air. The lowest temperature of the year at Isfjord Radio, —26.5 °C, was observed both on 23 and 25 December. In addition to advection of air from the Polar Basin, these days were characterized by a clear sky, no doubt leading to a considerable radiative heat loss of the ground.

Considering the average temperature conditions during the year, it appears from the tabulated data that January was exceptionally mild, forming a continuation in this respect of the conditions in the months of November–December of the preceding year. After a relatively cool February, practically all spring and summer months had above normal temperatures. This applies especially to Hopen and Bjørnøya. The high April temperature for Hopen equals that of April 1950. They are the highest means recorded for this month since observations started at Hopen in 1945. The last part of the year, on the other hand, was unusually cold, particularly the months of November and December.

Monthly mean temperatures for 1973 (T) and their deviations (d) from the means of the period 1947–72

		I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Isfjord Radio	T	–5.9	–12.9	–11.7	–6.7	–3.3	2.1	5.0	4.0	1.0	–5.0	–10.6	–13.7
	d	5.7	–1.3	0.8	2.6	0.1	0.5	0.4	–0.2	0.0	–1.9	–3.7	–4.3
Hopen	T	–5.7	–14.5	–12.7	–5.9	–3.4	0.8	4.0	3.3	1.5	–4.8	–14.4	–16.6
	d	7.7	–1.9	1.2	5.0	1.4	1.2	2.1	1.1	0.8	–1.9	–7.4	–6.2
Bjørnøya	T	–2.3	–7.6	–7.1	–4.0	–0.6	3.8	6.4	4.8	2.7	–1.3	–7.7	–7.8
	d	5.5	–0.4	0.8	1.5	0.9	1.9	2.2	0.5	–0.1	–1.2	–4.9	–2.2

Sea ice and drift speed observations in 1973

By Torgny E. Vinje

A survey of the sea ice distribution at the end of each month is shown in Figs. 1–12. The main source of data is the American satellite pictures, supplemented by observations from aircraft, Arctic weather stations, and ships. The observations have been plotted at Meteorologisk Institutt, Oslo.

By comparison of satellite pictures with surface observations, it has been found that a concentration less than 3/8 is not always registered on the satellite pictures.

Ice conditions north of Iceland have been close to normal in the last years after a gradual improvement since 1968. In Vesterisen (Fig. 2), the annual reoccurring features of Odden and Nordbukta, which may indicate a large-scale intermingling between the East Greenland Current and the water in the Norwegian Sea, in 1973 developed in the beginning of February and vanished towards the end of April. In March these features were almost as pronouncedly developed as they were at the end of March and April 1970 (Cf. Vinje, Norsk Polarinstitutt Årbok 1970).

There was exceptionally little ice along the west coast of Spitsbergen during the winter and spring of 1973. This is a continuation of the very favourable ice conditions found in this area at the end of 1972. In 1973 the west coast stayed more or less free of ice until the end of November, when the sea ice distribution became close to normal.

The favourable ice conditions in Østisen at the end of 1972 (Fig. 2), continued into 1973. Thus the southern ice edge was found at higher latitudes than normal during the first months of the year. From June on, the sea ice distribution in this area became close to normal.

The table below gives some average drift speed values for giant floes as well as for a small cluster of drift ice west of Spitsbergen. The figures have been obtained from the ESSA satellite pictures and the positions of the drift ice have been transferred to a map with the aid of a pantograph, using well marked points which could be identified in the different pictures.

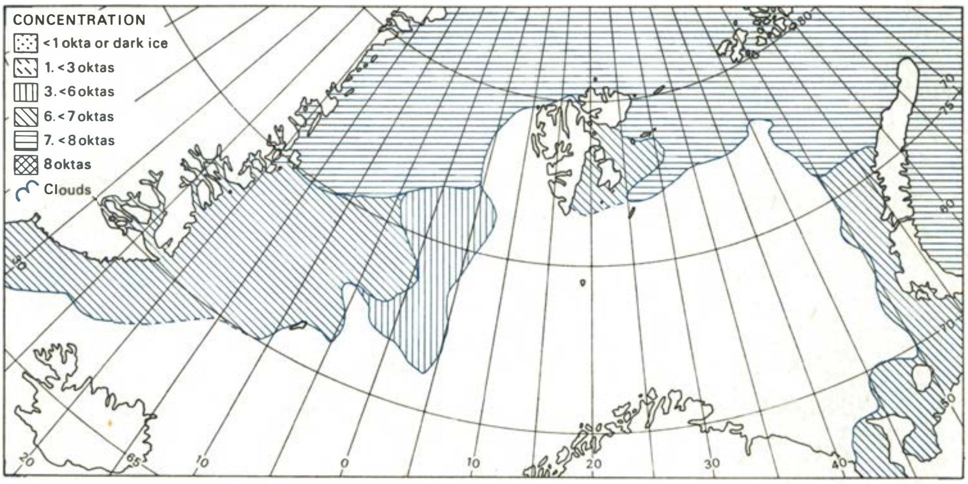


Fig. 1. *Sea ice distribution at the end of January.*

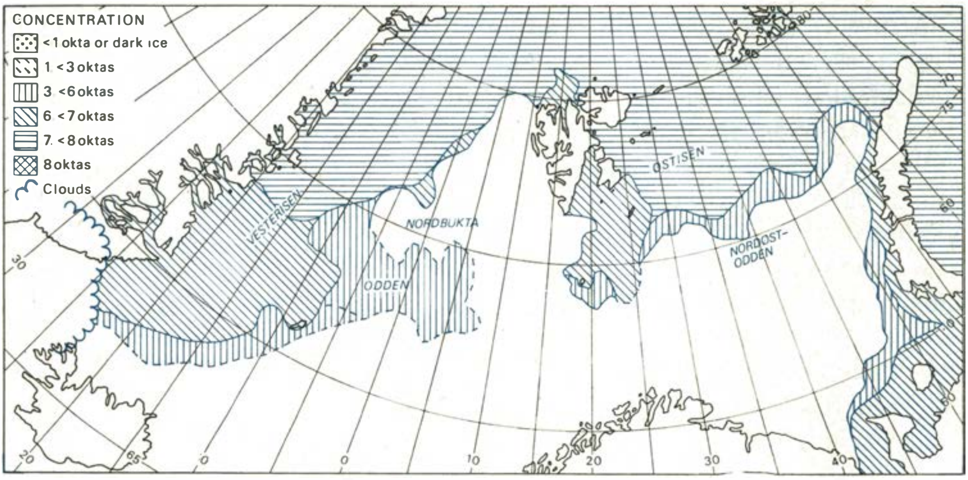


Fig. 2. *Sea ice distribution at the end of February.*

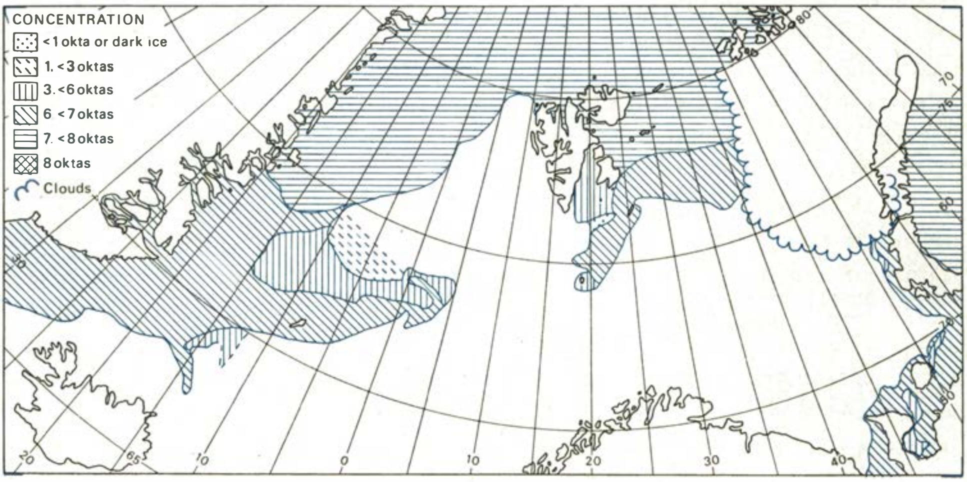


Fig. 3. *Sea ice distribution at the end of March.*

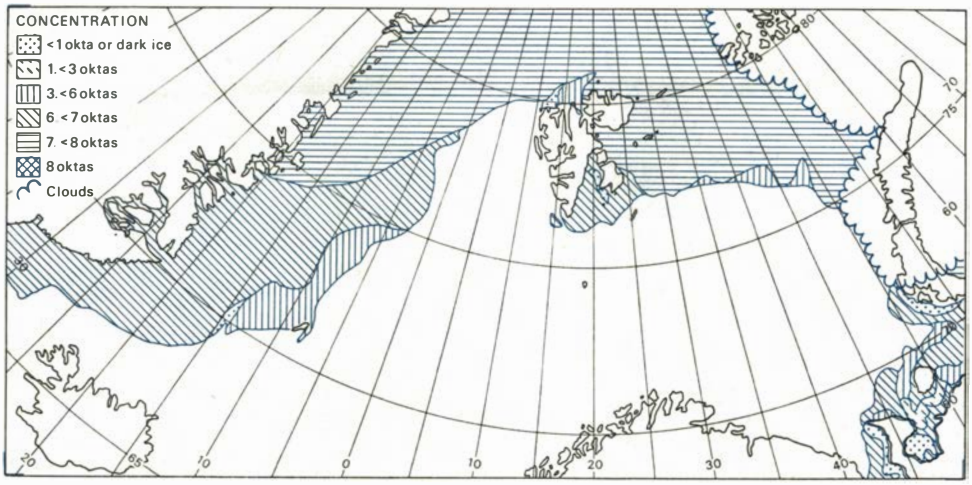


Fig. 4. *Sea ice distribution at the end of April.*

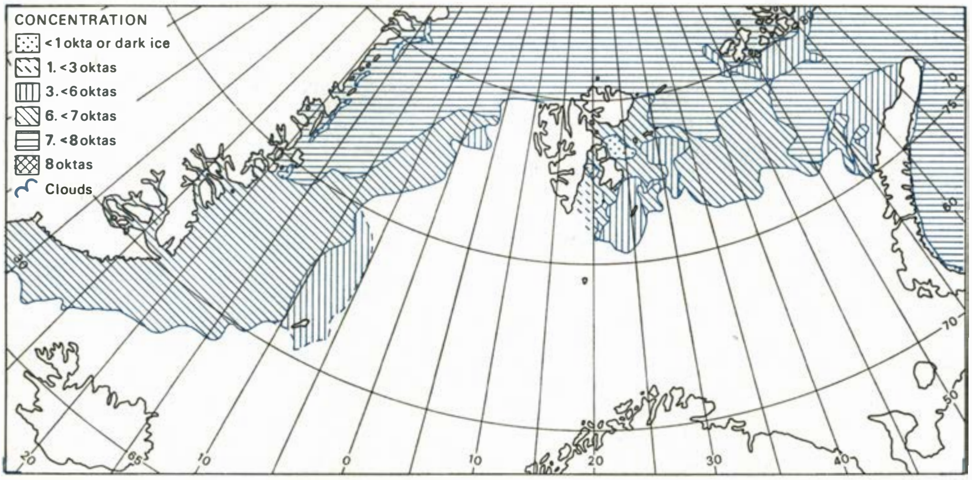


Fig. 5. *Sea ice distribution at the end of May.*

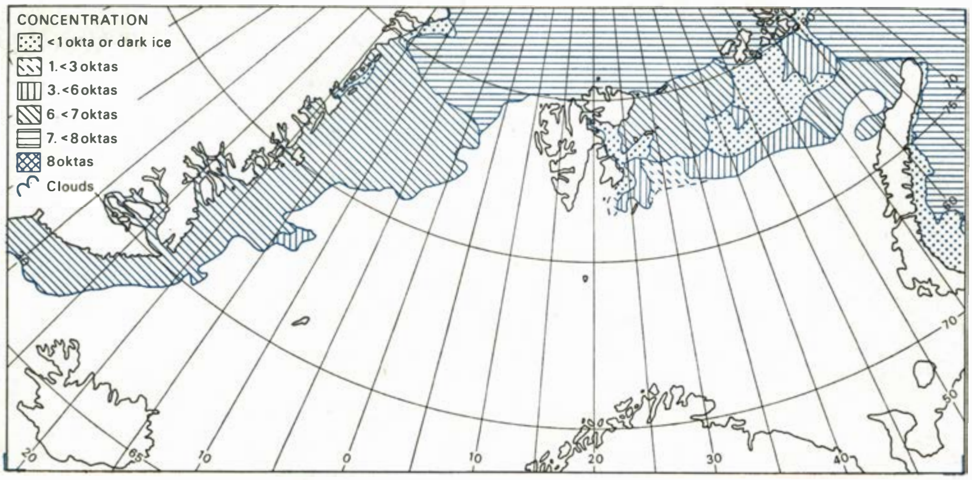


Fig. 6. *Sea ice distribution at the end of June.*

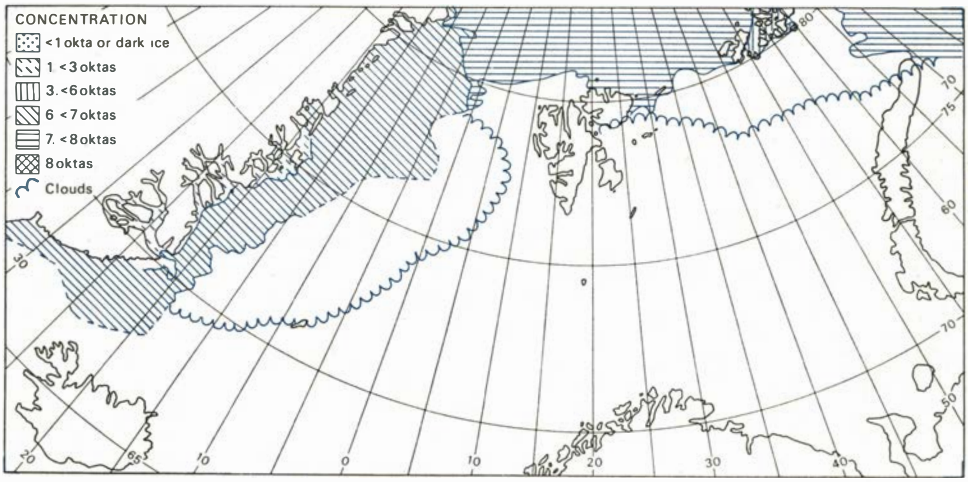


Fig. 7. *Sea ice distribution at the end of July.*

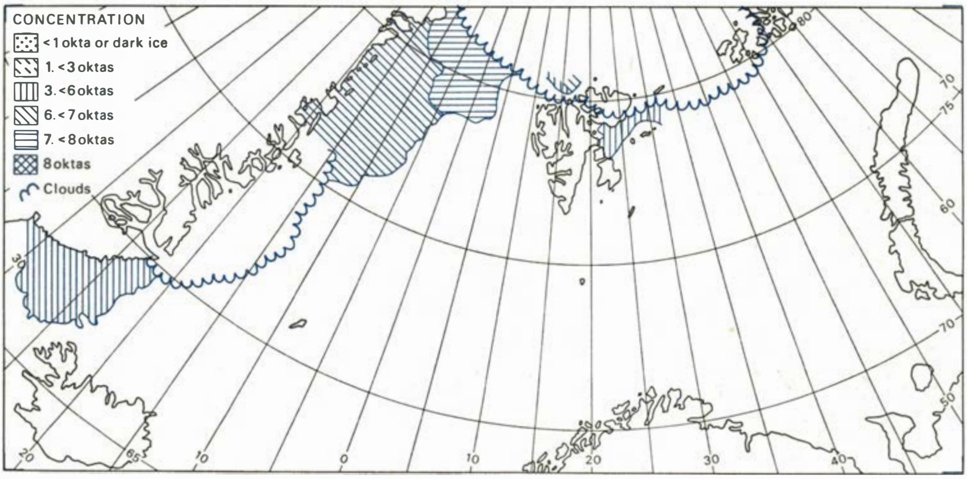


Fig. 8. *Sea ice distribution at the end of August.*

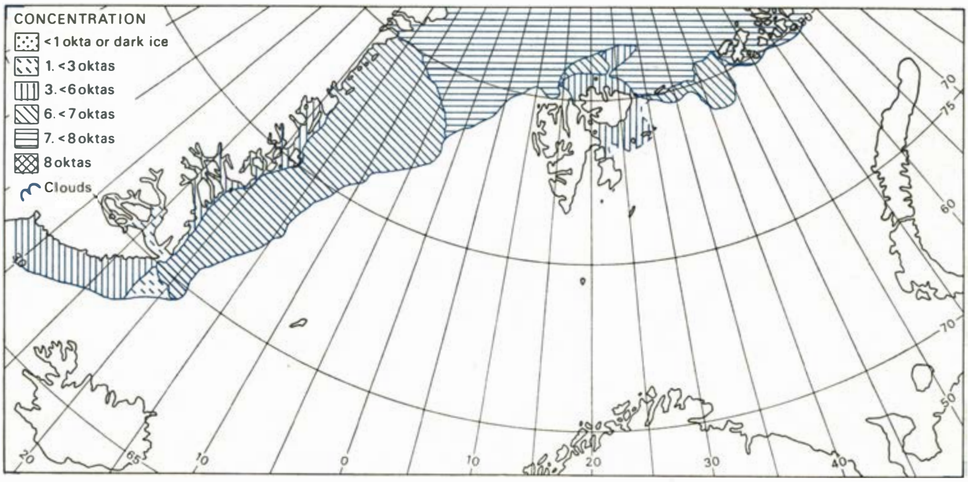


Fig. 9. *Sea ice distribution at the end of September.*

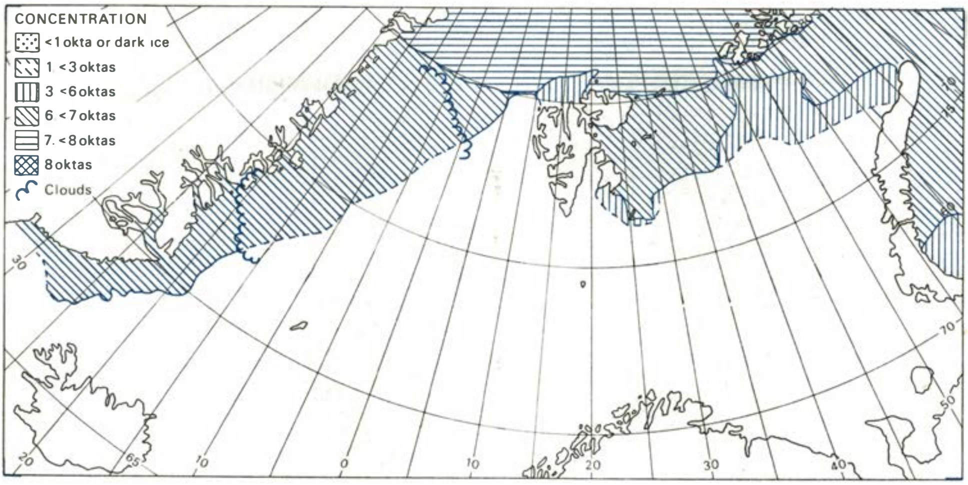


Fig. 10. *Sea ice distribution at the end of October.*

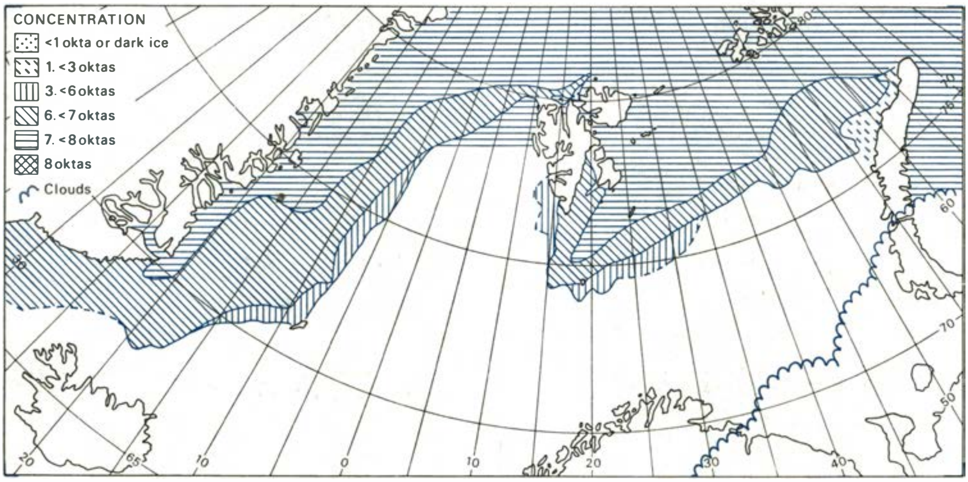


Fig. 11. *Sea ice distribution at the end of November.*

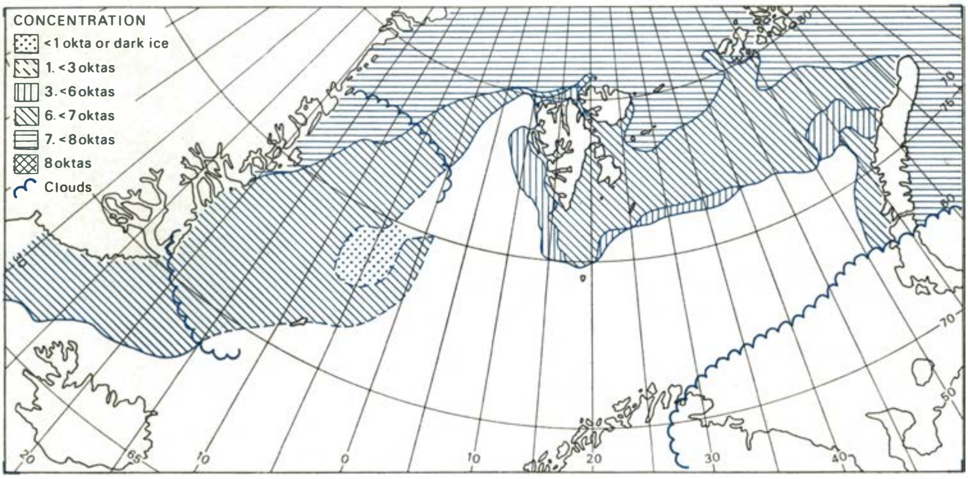


Fig. 12. *Sea ice distribution at the end of December.*

Position	Speed km/24h	Drift from	Period
72.8N–13W	6.7	N	13.IV–16.IV
74.8N–14W	15.1	NNE	13.IV–16.IV
78.8N–05W	17.1	NNE	23.V –28.V
79.5N–05W	19.8	NNE	23.V –28.V
78.8N–00	12.5	N	23.V –28.V
79.2N–02E	15.7	N	23.V –28.V
79.3N–03E	16.3	N	23.V –28.V
77.1N–13E	22.7	SE	10.V –14.V

The estimates referring to the East Greenland Current are within the range of estimates made in previous years (Cf. VINJE, Norsk Polarinstitutt Årbok 1968–1972). The drift speed of the sea ice in the cold current running north-westward along the coast of Spitsbergen is observed to be 22.7 km/24h for the period 10–14 May. The wind speed in the area ranged from 5 to 10 m/sec from NE and E in the same period. As this direction is almost perpendicular to the drift direction, most of the ice drift should be caused by the sea current.

Iakttagelser over dyrelivet på Svalbard i 1973

(*Observations of animal life in Svalbard 1973*)

(Наблюдения над фауной Свальбарда в 1973 г.)

Av Thor Larsen

Innhold

Abstract

In 1973 a new questionnaire for the fauna of Svalbard was distributed to Norwegian and foreign expeditions to Svalbard. The questionnaire has legends in Norwegian, English and Russian, and data can easily be transferred to punch cards for computer analysis. Filled-in questionnaires were received from twenty observers and expeditions.

More than 300 walrus were observed in northern and eastern Svalbard waters in 1973, indicating a population increase which may yield a viable population in these waters. The Svalbard reindeer is probably present in the Hornsund area. Due to the particular importance of the species, Long-tailed ducks, Eiders, Pink-footed geese, Brent geese, and Barnacle geese are listed in tables, while common birds are not included.

Аннотация

В 1973 г. нововыработанный тип анкетного бланка по свальбардской фауне с параллельной легендой на норвежском, английском и русском языках был в обильном числе экземпляров разослан норвежским и зарубежным организациям и лицам, намеревающимся снарядить экспедиции на Свальбард. Заполненные анкетные данные легко можно переводить на перфорационные карты для анализа на вычислительной мащине. Поступили заполненные бланки от 20 наблюдателей и экспедиций.

Более 300 моржей было обнаружено в северных и восточных свальбардских водах в 1973 г., что указывает на прирост стада этих зверей, могущий опеспечивать жизнеспособную популяцию их в этих водах. Свальбардский северный олень сейчас обитает в области залива Hornsund. Наблюдения следующих видов птиц приведены в списках ввиду их особого значения: морянка, гага, короткоклювый гуменник, черная и белощекая казарки, тогда как результаты наблюдений над обычными для Свальбарда птицами не изложены в таком обзорном виде.

Innledning

I 1973 tok Norsk Polarinstitutt i bruk nye observasjonsskjemaer for faunistiske registreringer på Svalbard. Kortene er i A5 format, halvstive, og med tekster på norsk, engelsk og russisk. Etter at kortene er fylt ut av observatørene, kodes informasjonene i ruter på samme kort, og kan så lett føres over til hullkort for senere databehandling. Kortene har vært delt ut til Norsk Polarinstitutts partier som besøkte Svalbard i 1973, samt til en rekke norske og utenlandske ekspedisjoner. Vi har fått kort tilbake fra 20 observatører/ekspedisjoner. Observasjonene kommer fra nær sagt hele Svalbard, med unntak av Spitsbergens østside, Hinlopenstredet og Nordaustlandet. Vanlige fugle- og pattedyrarter er ikke omtalt i denne oversikten, med mindre de opptrer utenfor sine vanlige utbredelsesområder, eller det er forhold som fortjener særlig omtale. Det foreligger mange observasjoner over ærfugl (*Somateria mollissima*), Svalbardrein (*Rangifer tarandus platyrhynchus*), moskus (*Ovibos moschatus*) og isbjørn (*Ursus maritimus*), men disse vil bli publisert i egne rapporter.

Observasjonene i 1973 er i alt vesentlig gjort i perioden mars—september. Et viktig observasjonsmateriale ble samlet inn i forbindelse med isbjørnundersøkelsene på Kong Karls Land i mars og april. Annet materiale av særlig verdi kommer fra det nordøstlige Svalbardfarvann ved Havforskningsinstituttet i Bergen, fra Nordenskiöld Land ved Zoologisk Museum i Bergen og fra Lurøya ved et av NP's slavepartier.

Takk

Jeg vil rette en takk til alle som har bidratt med opplysninger om fugle- og pattedyrobservasjoner på Svalbard i 1973. Rapporter er mottatt fra E. ALENDAL og I. BYRKJEDAL (EA/IB) fra Nordenskiöld Land, J. ANGARD (JA) fra Kongsøya, J. BAKKERUD (JB) fra Svenskøya, S. BARANOWSKI (SB) fra Hornsund, S. A. BENGTSSON (SAB) fra Ny-Ålesund, T. BENJAMINSEN og B. BERGFLØDT (TB/BB) fra farvannene nord og øst for Svalbard, AA. T. EKKER (AAE) fra NP's ekspedisjonsfartøy, E. E. JACKSON (EEJ) fra Hornsund, H. JØRNVALL (HJ) fra Longyearbyen, Y. OHTA (YO) fra St. Johnsfjorden, I. D. PENNIE (IP) fra Grønfjorden, O. PLANTEMA (OP) fra Ny-Ålesund, H. REMMERT (HR) fra Adventdalen, A. B. REYNOLDS (ABR) fra Prins Karls Forland, E. SENSTAD (ES) fra Dicksonfjorden og Kapp Wijk, instituttet SEVMORGEO i Leningrad (SEV) fra Wijdefjorden, Liefdefjorden og områdene rundt Barentsburg, P. STARK (PS) fra nordøstlige Svalbardfarvann, A. VAAG (AV) fra Lurøya, T. WINSNES (TW) fra Barentsøya og Edgeøya og B. WOLD (BW) fra Ny-Ålesund.

Pattedyr

Svalbardrein (*Rangifer tarandus platyrhynchus*): Den polske ekspedisjonen som arbeidet i Hornsundområdet registrerte «proofs» på rein i Hornsund, men det foreligger ingen meldinger om direkte observasjoner (BARANOWSKI 1974).

Fig. 1. *Mer enn tre hundre hvalross ble observert på Svalbard i 1973.*
More than three hundred walrus were observed in Svalbard in 1973.
Более трехсот моржей было замечено на Свальбарде в 1973 г.
Photo: T. FJELD

Den enslige reinsbukken på Svenskøya ble observert også våren 1973 (JB). Forøvrig foreligger et stort reinmateriale fra Nordenskiöld Land (EA/IB), men dette vil bli bearbeidet i sammenheng med planlagte reinundersøkelser av de samme i 1974.

Moskus (*Ovibos moschatus*): Flere observasjoner av moskus foreligger også fra Nordenskiöld Land (EA/IB), men disse vil også bli bearbeidet i sammenheng med fortsettelsen av undersøkelsene i 1974.

Isbjørn (*Ursus maritimus*): Det foreligger en rekke isbjørnobservasjoner fra de østlige og nordlige deler av Svalbard (JA, JB, TB/BB og PS) men disse blir delvis publisert annensteds i årboken, delvis samlet for senere bearbeidelse og publisering. En isbjørn ble observert i indre St. Johnsfjorden i midten av august (YO).

Steinkobbe (*Phoca vitulina*): Ett eksemplar ble rapportert fra Forlandsøyane primo juni (BW).

Hvalross (*Odobenus rosmarus*): Fra Moffen foreligger det flere meldinger om hvalrossflokker, til sammen ca. 40 dyr (AaE, BENJAMINSEN et al. 1973). Mer enn tre hundre hvalross ble observert ved Kvitøya av to uavhengige ekspedisjoner (PS, BENJAMINSEN et al. 1973). I dette området var det en del is, og hvalrossene ble sett i flere flokker (25–30). I ett tilfelle ble det observert 60 dyr på ett flak.

Det var forholdsvis mange unger blant dem. På Andréetangen (Edgeøya) ble det sett opptil 14 hvalross i løpet av sommeren (AaE), og fra området rundt Lurøya foreligger tre enkeltobservasjoner (AV). To hvalross ble også sett ved Ny-Ålesund i slutten av februar (BW).

Den plutselige økningen i hvalrossobservasjoner på Svalbard må henge sammen med en tilsvarende økning av bestanden. Økningen må høyst sannsynlig først og fremst tilskrives innvandring fra andre hvalrossplasser, antagelige fra Franz Josef Land. Med den vernestatus de østlige og nordlige områdene nå har fått, er det håp om at hvalrossen etter hvert vil bygge opp livskraftige bestander på Svalbard.

Hvithval (*Delphinapterus leucas*): Arten ble stadig observert i Kongsfjorden, fra tidlig på våren til medio august. Den opptrådte i flokker på mellom 5 og mer enn 100 individer (BW).

Fugler

Havsvale (*Hydrobates pelagicus*): To individer ble observert i Hornsunds munning 11/8 (JACKSON 1974). Dette er første gang arten er observert på Svalbard.

Krikkand (*Anas crecca*): En død hann ble funnet på Midtholmen, Kongsfjorden 16/8 (SAB).

Havelle (*Clangula hyemalis*): Se Tabell 1.

Ærfugl (*Somateria mollissima*): Observasjoner av større ansamlinger ærfugl er gjengitt i Tabell 2. Forøvrig foreligger en rekke observasjoner av flokker på opptil 50 individer.

Praktærfugl (*Somateria spectabilis*): Fire hunner ble observert ved Sveltihjel 26/7. En hann ble sett ved Elveneset og to hanner vest for Deltaneset 22/7 (EA/IB).

Kortnebbgås (*Anser fabalis brachyrhynchus*): Se Tabell 3.

Ringgås (*Branta bernicla hrota*): Se Tabell 4.

Hvitkinngås (*Branta leucopsis*): Se Tabell 5.

Svalbardrype (*Lagopus mutus hyperboreus*): Flere observasjoner foreligger fra strekningen Deltadalen—Grøndalen (EA/IB). Her ble blant annet sett fem egg- og ungekull på fra fire til ni, gjennomsnitt 4,6. I Ny-Ålesundsområdet ble det også funnet fem kull på mellom fem og tolv unger, gjennomsnitt 8,4 (SAB).

Tjeld (*Haematopus ostralegus*): To individer ble observert i Grønfjorden 26/6 (IP). 10 til 15 individer ble sett på Bjørnøya 21/7 (TB/BB).

Sandlo (*Charadrius hiaticula*): Seks individer ble sett i Grønfjorden i juni og juli (IP). På strekningen Sassendalen—Grønfjorden ble det observert i alt 26 individer, både voksne og unger, i juli og august (EA/IB). To par ble observert ved Longyearbyen 2/8, og minst fem par med unger var ved Ny-Ålesund 3–16/8 (SAB).

Steinvender (*Arenaria interpres*): Ved Ny-Ålesund hekket minst fem par (OP), og tre voksne og tre unger ble sett 16/8 (SAB). Ett individ ble sett ved Kapp Wijk 6/7 (ES).

Svarthalespove (*Limosa limosa*): Ett individ er rapportert fra Adventdalen 26/7 (HR). Såvidt vites er dette første gangs observasjon av arten fra Svalbard.

Lappspove (*Limosa lapponica*): Ett individ ble sett på Lurøya 6/8 (AV).

Myrsnipe (*Calidris alpina*): En ungfugl ble sett ved Kapp Laila 19/8 og to voksne individer i Colesbukta 24/8 (EA/IB). To voksne individer ble sett på Kvadehuken 14/7 (OP).

Sandløper (*Crocethia alba*): Ved Ny-Ålesund ble det funnet ett reir med tre egg 25/6, og ett voksent individ med tre unger ble sett 19/7 (OP). Den 6/8 ble to voksne og tre unger sett i samme område (SAB). Ett individ ble observert ved Kapp Wijk 30/6 (ES).

Polarjo (*Stercorarius pomarinus*): En flokk på 30 voksne og ungfugl ble observert på Halvmåneøya 25/8 (AaE).

Fjelljo (*Stercorarius longicaudatus*): To individer ble sett ved Gluudneset, Kongsfjorden 25/6, og to individer ble sett på Kvadehuken 14/7 (OP). Ett individ ble sett på Kapp Wijk 3/7 (ES), ett ved Skarverypehøgda, Sassendalen 23/7 (EA/IB), og tre ved Ossian Sarsfjellet 7/8 (SAB).

Storjo (*Catharacia skua*): To par hevdet territorier på Dunøyane i juli—august (JACKSON 1974). Ett individ ble sett på Gluudneset 26/6 og ett på Kvadehuken 14/7 (OP). Ett individ ble også sett på Kapp Wijk 12/7 (ES). To individer ble observert på Forlandsøyane 3/8 (TB/BB). Ett individ ble sett ved Ny-Ålesund 2/9, og ett ved Bjørnøya 4/9 (AaE).

Svartbak (*Larus marinus*): Ett dødt individ ble funnet på Blomstrandhalvøya 2/7 (OP). Ett individ ble observert på Forlandsøyene 3/8 (TB/BB).

Hettemåke (*Larus ridibundus*): To eksemplarer ble sett ved Longyearbyen 21/7 (HJ).

Sabinemåke (*Xema sabini*): Ett individ ble observert i en flokk med krykkjer sørøst av Kapp Mohn, Nordaustlandet (TB/BB).

Snøugle (*Nyctea scandiaca*): Ett individ ble observert i Engelskbukta i april (BW).

Gråtrost (*Turdus pilaris*): Ett dødt individ ble funnet på Kapp Wijk 22/6 (ES).

Steinskvett (*Oenanthe oenanthe*): Fire voksne individer med unger ble observert ved gruve 7 den 23/7 (HR). To voksne og to unger ble sett i Colesdalen 13/8 og ett voksent individ ved Colesbukta 24/8 (EA/IB). En ungfugl ble sett ved Ossian Sarsfjellet 7/8 (SAB).

Tabell 1

Observasjoner av havelle (Clangula hyemalis) *på Svalbard sommeren 1973.*

(Observations of Long-tailed duck in Svalbard in the summer of 1973)

(Наблюдения морянок на Свальбарде летом 1973 г.)

Lokalitet/dato Locality/date Местность/дата	*Antall* Number Число	*Observatør/anmerkninger* Observer/remarks Наблюдатель/примечания
Gerdøya 2–5/7	7 par	OP
Brandalpynten 7/7	15 hanner	OP
Coraholmen 18/7	60 individer	ES
Kapp Martin 23/7	3 voksne	AV
Ny-Ålesund 3–13/8	45 voksne, 5 unger	SAB
Andréetangen 18/8	40 voksne	AaE
Nebbodden, august	350 hekkende individer	Jackson 1974

Tabell 2

Observasjoner av større ansamlinger ærfugl (Somateria mollissima) *på Svalbard sommeren 1973. Flokker mindre enn 50 ind. er ikke medregnet.*

(Observations of large flocks of Eiders in Svalbard in the summer of 1973. Flocks less than 50 birds are not listed.)

(Наблюдения крупных стай гаг на Свальбарде летом 1973 г. Не включены в список стаи, в которые входит меньше 50 особей.)

Lokalitet/dato Locality/date Местность/дата	*Antall* Number Число	*Observatør/anmerkninger* Observer/remarks Наблюдатель/примечания
Prins Heinrichøya 27/6	ca. 160 voksne	OP Hekkende
Juttaholmen 28/6	ca. 400 «	OP Hekkende
Gerdøya 4–7/7	ca. 250 «	OP Hekkende 75 reir, 4–5 egg
Delitschøya 21/7	ca. 500 «	AaE
Diskobukta 28/7	ca. 470 «	AaE
Kapp Lee 28/7	ca. 100 «	AaE
Freemansundet 28/7	ca. 250 «	AaE
Øst Freemansundet 3/8	ca. 300 «	AaE

Tabell 3

Observasjoner av kortnebbgås (Anser fabalis brachyrhynchus) *på Svalbard sommeren 1973.*

(Observations of Pink-footed geese in Svalbard in the summer of 1973)

(Наблюдения короткоклювых гуменников на Свальбарде летом 1973 г.)

Lokalitet/dato Locality/date Местность/дата	*Antall* Number Число	*Observatør/anmerkninger* Observer/remarks Наблюдатель/примечания
Agardhbukta 25/6	2 voksne	AaE
Gerdøya 2–5/7	4 voksne	OP, 2 hekkende par
Brøggerhalvøya, juni/juli	13 individer	OP
Flintholmen 18/7	ca. 60 individer	ES
Coraholmen 18/7	28 voksne	ES
Kapp Wijk 19/7	ca. 13 voksne	ES
St. Johnsfjorden juli	7 voksne, 14 unger	YO
Trehøgddalen 24/7	—	EA/IB, 4 ødelagte reir
Elveneset 1/8	25 voksne, 16 unger	EA/IB
Fuglefjella 17/8	8 voksne, 6 unger	EA/IB
Grønfjorden 19/8	35 voksne og unger	EA/IB
Grøndalen 20/8	13 individer	EA/IB
Kapp Laila–Hollendardalen 23/8	16 individer	EA/IB
Colesbukta 24/8	7 individer	EA/IB
Colesdalen 26/8	20 individer	EA/IB
Vindodden 31/8	30–35 individer	EA/IB
Forlandsøyane 3/8	70 voksne og unger	TB/BB
Vårfluesjøen 6/8	20–25 voksne	TB/BB

Tabell 4

Observasjoner av ringgås (Branta bernicla hrota) *på Svalbard sommeren 1973*

(Observations of Brent geese in Svalbard in the summer of 1973)

(Наблюдения черных казарок на Свальбарде летом 1973 г.)

Lokalitet/dato Locality/date Местность/дата	*Antall* Number Число	*Observatør/anmerkninger* Observer/remarks Наблюдатель/примечания
Kapp Martin 23/7	4 voksne, 3 unger	AV
Forlandsøyane 3/8	40 voksne, 10 unger	TB/BB
Hornsund juli/august	—	JACKSON 1974. Obs., men ikke hekkende.
Lurøya 15/8–3/9	Max. 53 individer hvorav 20 unger. 35 individer 3/9	AV Ca. 10–15 reir ble funnet, men forbehold om forveksling med ærfuglreir, som ble funnet i ant. 25–35.
Halvmåneøya 24/8	ca. 90 voksne	AaE
Halvmåneøya 25/8	40 voksne	AaE

Tabell 5
Observasjoner av hvitkinngås (Branta leucopsis) *på Svalbard sommeren 1973.*
(Observations of Barnacle geese in Svalbard in the summer of 1973)
(Наблюдения белощеких казарок на Свальбарде летом 1973 г.)

Lokalitet/dato Locality/date Местность/дата	*Antall* Number Число	*Observatør/anmerkninger* Observer/remarks Наблюдатель/примечания
Forlandsøyane primo juni	ca. 300 voksne	BW
Skarverypehøgda 23/7	81 voksne 34 unger	EA/IB
Deltadalen 26/7	6 voksne	EA/IB Minst 2 reir
Colesbukta 23–25/7	79 individer	EA/IB
Freemansundet 27/7	50 voksne 10 unger	TW
Freemansundet 29/7	2 voksne	AaE
Dunøyane juli/aug.	1457 voksne	JACKSON 1974. 416 ble merket, hvorav to hvite (albino?), alle «non-breeders».
Lurøya 15/8	3 individer	AV

Litteratur

BARANOWSKI, S., 1974: *Report on the field work of the Polish scientific expediton to Spitsbergen in 1973.* Universytet Wroclawski Im Boleslawa Bierula. Wroclaw. 25 pp.

BENJAMINSEN, T., B. BERGFLØDT og T. ØRITSLAND, 1973: Selundersøkelser i det nordlige Atlanterhav i 1973. *Fiskets Gang* **59**, 853–863.

JACKSON, E. E., 1974: Spitsbergen 1973. *The Wildfowl Trust Bulletin* **68**, 6–8.

Norsk Polarinstitutts virksomhet i 1973

AV TORE GJELSVIK

Organisasjon og administrasjon

PERSONALE

Norsk Polarinstitutt hadde 34 faste stillinger i 1973, 1 mer enn foregående år. Pr. 31/12 var en ny stilling som geolog II (kvartærgeolog) ubesatt. BJARNE EVENSEN fratrådte sin stilling som tegner I 31/12. KJELL JOHANSEN fratrådte sin stilling som kontorfullmektig II 30/11. PER JOHANSEN ble ansatt som kontorassistent fra 26/11.

Midlertidig engasjerte:

ANDERSEN, LIV KRUGE, redaksjonssekretær. Til 15/1.
BREKKE, ANNEMOR, redaksjonssekretær. Fra 5/2.
EDWARDS, MARC B., Ph.D. (lønnet av NTNFK på Barentshavprosjektet)
HUSETH, ROLF EGIL, assistent
KNUDSEN, ELSA, kontorassistent
KRISTENSEN, IVAR RENDAL, cand.mag.

Stipend og forskningsbidrag er ytt til:

Cand.real. EINAR ALENDAL, stipend til dekning av utgifter vedrørende undersøkelser av rein og moskus på Svalbard.

Cand.real. KARL HAGELUND, bidrag til bearbeidelse av materiale vedrørende ærfuglbestanden på Kapp Linné.

Longyearbyen Jeger & Fiskerforening, bidrag til foreningens arbeid med observasjoner og registrering av vilt på Svalbard.

Cand.mag. KJELL REPP, stipend til dekning av utgifter vedrørende breundersøkelser ved Ny-Ålesund.

Universitetet i Trondheim og Det Kgl. Norske Videnskabers Selskab, bidrag til delvis dekning av utgifter til biologisk ekspedisjon til Svalbard sommeren 1973.

Cand.real. PER WEGGE, stipend til dekning av utgifter vedrørende elektroforeseanalyser av isbjørnserum.

Cand.mag. KARI AASGAARD, stipend til dekning av reise- og oppholdsutgifter i Ny-Ålesund i forbindelse med feltarbeider.

Oppnevnelser og tillitsverv:

THOR LARSEN til (1) norsk representant i IUCN Survival Service Commission, (2) varamann til IUCN's Arctic Environment Specialist Group, (3) medlem av Den norske forhandlingsdelegasjon til konferansen om en internasjonal isbjørnavtale.

OLAV LIESTØL til medlem i det norske planleggingsutvalget for International Hydrological Program.

HARALD MAJOR til varamann i Ligningsrådet for Svalbard for perioden 1973/75.

OLAV ORHEIM til (1) medlem av rådet for International Glaciological Society, (2) formann i Nordisk Seksjon av International Glaciological Society.

THOR SIGGERUD til varamann i Nasjonalkomitéen for International Union of Geological Sciences.

TORGNY VINJE til (1) medlem av NTNF's fagkomité for isdata, (2) formann i den norske POLEX-komitéen, (3) medlem i den norske GARP-komitéen.

DAVID WORSLEY som formann i Norsk Paleontologisk Forening.

REGNSKAP FOR 1973

Kap. 950. Poster:	*Bevilget:*	*Medgått:*
1. Lønninger	kr. 2.492.000	kr. 2.471.700
9. Deltakelse i Antarktisekspedisjon	« 95.000	« 19.200
10. Kjøp av utstyr	« 35.000	« 32.600
15. Vedlikehold	« 3.000	« 900
20. Ekspedisjoner til Svalbard og Jan Mayen	« 1.365.000	« 1.360.800
29. Andre driftsutgifter	« 1.021.000	« 1.031.500
30. Innredningsarbeider	« 50.000	« 43.900
70. Stipend	« 45.000	« 45.000
	kr. 5.106.000	kr. 5.005.600

Kap. 31. Fyr og radiofyr på Svalbard	kr. 36.000	kr. 38.200

Kap. 340. Forskningsstasjonen på Svalbard:		
9. Driftsutgifter	kr. 323.000	kr. 257.200
10. Inventar og utstyr	« 50.000	« 49.800
	kr. 373.000	kr. 307.000

Kap. 3950. Inntekter:	*Budsjettert:*	*Innkommet:*
1. Salgsinntekter	kr. 80.000	kr. 47.000
2. Refusjon fra Svalbardbudsjettet	« 550.000	« 550.000
3. Tilfeldige inntekter	« 20.000	0
	kr. 650.000	kr. 597.000

Kap. 4909. Tilfeldige inntekter:	kr. 0	kr. 790

Kommentar til regnskapet
Kap. 950.

Post 9. Deltakelse i Antarktisekspedisjon. – Mindreforbruket skyldes for liten bevilgning for en egen ekspedisjon og at man ikke fant mulighet for deltakelse i andre ekspedisjoner med adekvate oppdrag.

Feltarbeid

NORGE

Breundersøkelser

Undersøkelsene i Norge ledes av O. LIESTØL. De rutinemessige målinger av breenes massebalanse på Storbreen og Hardangerjøkulen ble utført av ham. På Folgefonni fortsatte cand.real. ARVE TVEDE balansemåling av Blomsterskardbreen. Både Hardangerjøkulen og Blomsterskardbreen viste et overskudd vesentlig på grunn av den store vinternedbør. Storbreen var omtrent i balanse.

Målinger av bretungenes lengdevariasjoner ble foretatt på 11 steder: 2 ved Folgefonni, 2 i Jotunheimen, 4 ved Jostedalsbreen, 2 på Møre og 1 i Svartisen. Ingen bre viste fremgang, 4 viste stillstand og 7 tilbakegang. Størst var tilbakegangen på Stegholtbreen i Jostedalen med 30 m.

SVALBARD

Norsk Polarinstitutts sommerekspedisjon til Svalbard ble organisert og ledet av operasjonssjef T. SIGGERUD og omfattet 33 personer, foruten besetningene på ekspedisjons- og hydrograferingsfartøy og helikoptre. Det lave antall deltakere skyldes at den sterke prisutvikling i forbindelse med ekspedisjonsbudsjettet har gjort en nedskjæring her nødvendig. Av deltakerne var 13 instituttets faste medarbeidere, 6 var engasjerte fagmedarbeidere og 14 assistenter.

To biologer fra Universitetet i Bergen fikk assistanse av ekspedisjonen og arbeidet i området sør for Isfjorden.

I mars-april sendte Norsk Polarinstitutt en ekspedisjon på fire mann til Kong Karls Land for undersøkelser av isbjørnhi. Disse gruppene var i stor grad finansiert utenom ekspedisjonsbevilgningen og er derfor ikke regnet med i hovedekspedisjonens deltakerantall.

Hovedvekten av arbeidet ble lagt i de østlige og sydøstlige deler med hydrografering, topografiske målinger og geologiske arbeider. Hydrografisk aktivitet var det også i Isfjorden, geofysiske arbeider i Ny-Ålesund og geologiske undersøkelser på Bjørnøya, Oscar II Land og Sørkapp. Ekspedisjonens planlagte program ble gjennomført.

Ekspedisjonsfartøyet M/S «Norvarg» med kaptein OLAV JOHANNESEN og 13 manns besetning ble overtatt i Tromsø 16/7. På grunn av tekniske problemer ble ekspedisjonsutstyret og ekspedisjonsdeltakerne først tatt ombord i Bodø om morgenen 18/7. 16/8 hentet ekspedisjonsfartøyet drivstoff for helikoptrene i

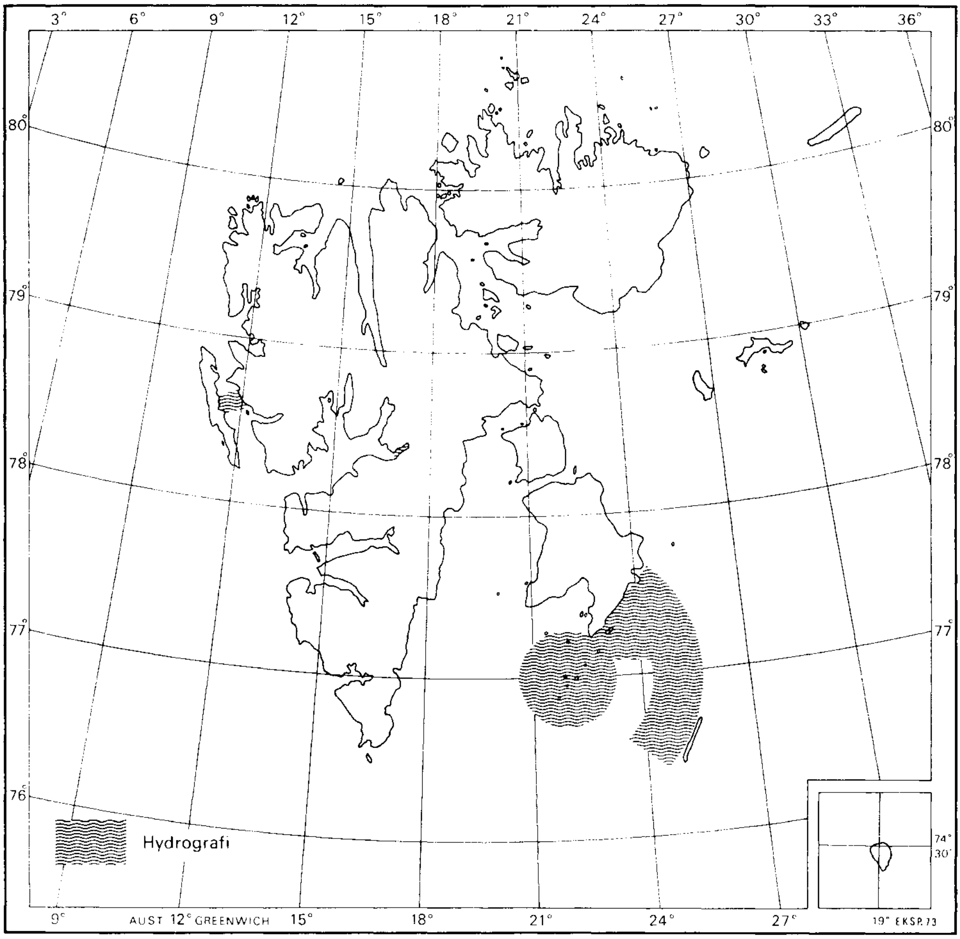


Fig. 1. *Oppoddet areal i 1973.*

Hammerfest. Ekspedisjonsutstyret ble losset og deltakerne gikk fra borde i Bodø 6/9.

R/K «Sjøfareren» med kaptein MORTEN HANSEN og seks manns besetning ble leiet av Norsk Selskab til Skibbrudnes Redning for hydrografering i området ved Tusenøyane. Fartøyet ble overtatt av hydrograf CHRISTIANSEN i Bodø 16/7 og avlevert samme sted 8/9.

Til transporter fra M/S «Norvarg» og ut i felten var 2 Bell 47 J helikoptre med 2 flyvere og en mekaniker leiet fra Helikopter Service A/S. Fartøyet satte først ut geologpartiet OHTA i Forlandssundet, hentet helikoptrene som var kommet med kullbåt til Longyearbyen, og gikk videre til Storfjorden. Det ble her utført endel topografiske arbeider. Disse ble senere fortsatt på Barentsøya og Edgeøya. På disse øyene ble også utsatt og flyttet geologparti WINSNES. Videre ble det utført endel flyvning på Barentsøya for Miljøverndepartementets naturvernkonsulent for Svalbard. På Kong Karls Land ble topografiske arbeider fullført og geologparti WORSLEY satt ut og senere hentet ved sesongens avslutning. Fra Kong Karls Land gikk M/S «Norvarg» rundt nordsiden av Spitsbergen via Ny-Ålesund til Longyearbyen hvor helikoptrene ble landsatt for hjemsendelse med kullbåt. Under hjemreisen ble geologparti EDWARDS hentet på Sørkapp. Under hele ekspedisjonen ble det gjort biologiske registreringer fra ekspedisjonsfartøyet, delvis også ved bruk av helikoptre og småbåt.

I sommerens løp ble det eksperimentert endel med radio, antenneutstyr og radioforbindelser, for å gjøre sambandet, som tildels er et stort problem på disse høye nordlige bredder, så effektivt og sikkert som mulig. I løpet av ekspedisjonen ble flere hytter i det østlige og nordlige området inspisert og reparert.

Værforholdene var ikke særlig avvikende fra normalen, men sterk vind i klarværsperioder hemmet flyvningene. Tåkeperioder var det som vanlig.

Issituasjonen var helt uvanlig med ingen is størstedelen av sommeren. Dette førte til overraskende problemer for ekspedisjonen, da dønningene i flere tilfeller hindret operasjoner med helikoptrene fra helikopterdekket ombord. Arbeidet ble derfor stadig sinket fordi man måtte oppsøke roligere farvann.

Hydrografi

I feltsesongen (18/6—5/9) utførte HELGE HORNBÆK, assistert av SIVERT UTHEIM og INGE FJELD, med hydrograferingsbåten «Svalis» lodding i Tempelfjorden og i Forlandssundet syd for Forlandsrevet.

Hydrograferingstoktet i år, med R/K «Sjøfareren», ble ledet av J. H. CHRISTIANSEN. E. NETELAND hadde tilsyn med vedlikehold av HI-FIX-systemet og annet elektronisk utstyr.

Som assistenter hadde man ARNE VAAG og IVAR RENDAL KRISTENSEN på Lurøya og JAN HAUGLAND og BJØRN JAKOBSEN på Hopen til å passe HI-FIX-slavestasjonene.

På grunn av den meget gunstige issituasjonen og et fartøy med utmerkede manøvreringsegenskaper og størrelse ble det besluttet å prøve å lodde ferdig det meget utsatte og vanskelige området mellom Tusenøyane. HI-FIX-slavestasjonene, som ble etablert på Lurøya og på Hopen, var på luften 1/8 og opploddinger ble påbegynt med Lurøya som sentrum. I alt ble det loddet ca. 5 200 naut. m. med en linjeavstand på 10 lanes (ca. 800 m).

Geodesi-topografi

O. STEINE (leder), J. BJØRKE, J. SUNDSBY og de engasjerte landmålerne DAG BJØRKEDAL og YNGVE V. JOHANSEN utførte de geodetiske og topografiske feltarbeidene. Assistenter var: HÅKON AUSTREM, TORMOD HOLTH NILSEN, IVAR HORVLI, TORSTEIN FJELD og CAMPBELL DAY.

Oppgaven var å utvide triangelnettet og å måle inn passpunkter på flyfoto for kartlegging i M = 1:100 000. Målingene ble utført på nord- og vestsiden av Agardhbukta (Spitsbergen), Barentsøya, størstedelen av Edgeøya og Kong Karls Land. HI-FIX-stasjonene på Ryke Yseøyane og på Svenskøya ble knyttet til det trigonometriske nettet. Til transport ble brukt helikopter.

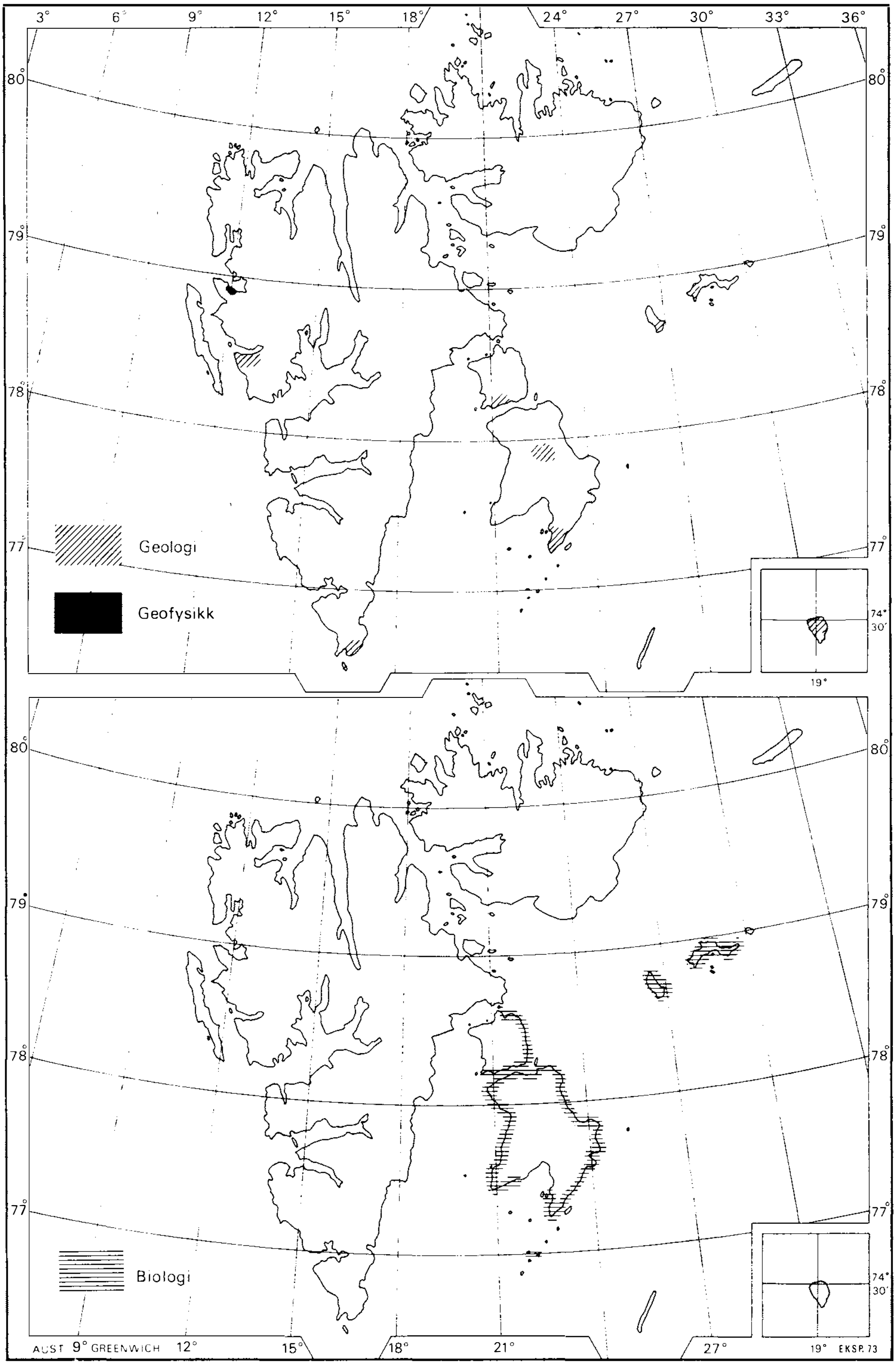


Fig. 2. *Geologiske, geofysiske og biologiske arbeidsområder i 1973.*

Geologi

I det geologiske feltarbeidet på Svalbard deltok fire geologpartier.

Y. OHTA med assistentene TERJE ANDRESEN og ROLF NYLEND arbeidet i Oscar II Land syd for St.Jonsfjorden i tiden 21/7—2/9. Arbeidet ble konsentrert om kartlegging og undersøkelser av Hecla Hoek bergarter og lag fra karbontiden.

T. S. WINSNES med assistent ØYVIN LAUTEN arbeidet på Barentsøya og Edgeøya i tiden 24/7—4/8, med geologisk kartlegging og stratigrafiske undersøkelser, spesielt av lag fra undre trias.

D. WORSLEY og M. B. EDWARDS med assistentene ATLE MØRK og HANS AUGEDAL undersøkte Bjørnøyas øvre paleozoiske lagrekke i tiden 19/7—17/8. M. B. EDWARDS reiste deretter sammen med assistentene til Sørkappland, hvor han arbeidet med undersøkelser av mezoiske avsetninger til 4/9. WORSLEY, assistert av LAUTEN, reiste fra Bjørnøya til Edgeøya og senere til Svenskøya og Kongsøya, hvor de i tiden 21/8—31/8 gikk opp detaljerte geologiske profiler.

Geofysikk

Målingene av massebalansen på breene i Ny-Ålesund fortsatte i 1973. Ved siden av disse undersøkelsene er det i 1973 på samme sted satt i gang en omfattende og detaljert undersøkelse av de glaci-hydrologiske forhold i et representativt område. BJØRN WOLD og KJELL REPP (hovedfagsstudenter) har deltatt i undersøkelsene og utført mesteparten av det praktiske arbeid.

V. HISDAL oppholdt seg ved Forskningsstasjonen i Ny-Ålesund i tiden 6/7—3/8 og startet opp en rekke intensitetsmålinger av den direkte solstråling i tre forskjellige bølgebånd. Så ofte værforholdene tillot, ble også globalstrålingens og himmelstrålingens spektralfordeling registrert. Det ble videre tatt en del nedbørsprøver for senere analyse i USA.

T. VINJE oppholdt seg samme sted fra 20/7—20/8. Han foretok kalibrering av strålingsinstrumenter både i kort- og langbølgeområdet og monterte et nytt albedometer. For å sikre den nødvendige kontinuitet i registreringene, ble det i slutten av 1973 også montert en punktskriver ved stasjonen. Strålingsstasjonen anses etter dette å være utbygget for registrering av de vesentlige strålingskomponenter som er av klimatisk interesse.

Fyr og radiofyr

Ettersyn av fyr og radiofyr ble foretatt i tiden 21/8—26/8 av NETELAND, assistert av ekspedisjonsdeltakere og besetning på R/K «Sjøfareren». Fyrene på Festningen, Rundodden og Bellsund (Kapp Martin) ble bygget om fra gass til batteridrift. Det samme vil senere bli gjort med de resterende gassfyr.

For å få erfaring med andre former for energiforsyning til fyrene, ble en vindgenerator innkjøpt og montert på prøve ved Forskningsstasjonen i Ny-Ålesund.

JAN MAYEN

O. ORHEIM foretok i tiden 16/8—23/8 massebalansemålinger på Sørbreen, Jan Mayen, idet reisen ble ordnet av Forsvarets Fellessamband. Kontrollmålinger av staker foretas ellers av personell fra Loran-stasjonen der.

Arbeid ved avdelingene

(se også under publikasjoner)

Administrasjonen

I samarbeid med fagkollegiet ble utarbeidet Norsk Polarinstitutts perspektivanalyse av 1973, samt en langtidsplan 1974/78 til bruk under budsjettarbeidet.

Hydrografi

Redaksjonelle arbeider ble foretatt på nytt sjøkart 522 og på nye utgaver av 502, 505 og 509. Forberedelse ble gjort til trykking av nye opplag av sjøkartene 504 og 510.

I samarbeid med NTNFK ble det gjort forberedelser for utlegging av loddskuddsdata fra datalogger.

I forbindelse med langtidsleie av M/S «Olav Scheel» har avdelingen i samarbeid med overingeniør TH. SØNDENAA utarbeidet spesifikasjoner over nødvendig ombygging av fartøyet. Videre er det foretatt vurdering og bestilling av nytt elektronisk utstyr til fartøyet.

Geodesi-topografi

Justering av det geodetiske nettet på Svalbard har pågått siden resultatene av dopplerobservasjonene i 1971 forelå. En del beregninger av sommerens målinger er utført. Arbeidet med stedsnavn på Svalbard fortsetter, og en ny utgave av kartet Svalbard 1:1 000 000 er ferdig. Kartblad B4 Reinsdyrflya, B5 Woodfjorden og deler av C8 Billefjorden er konstruert.

Avdelingen fortsetter arbeidet med stedsnavn, diverse kartblad og navnekart av Dronning Maud Land. L4 Schirmacheroasen og M4 Starheimtind i serien Dronning Maud Land 1:250 000 er fullført. En del andre kart i samme serien er under arbeid, bl.a. er N5 Forposten og N6 Sarkofagen ferdige til korrekturlesing.

Geologi

H. MAJOR fortsatte kullpetrografiske studier av prøver fra gruve 3, 4 og 7 i Longyearbyen. Han bearbeidet og innleverte rapporter om kullforekomster på Svalbard til World Energy Conference 1973, og besvarte diverse forespørsler angående Svalbards økonomiske geologi.

T. S. WINSNES utarbeidet en oversikt over Svalbards geologi til et symposium om olje og gass i Le Havre i mai. Som forberedelse av sommerens ekspedisjon utførte han fotogeologiske studier av Edgeøya og Barentsøya og etter hjemkomst bearbeidet han fossilmateriale samlet i løpet av sommeren. Han hadde forskjellige administrative oppgaver bl.a. ved fagkollegiets utarbeidelse av perspektivanalysen for instituttet.

A. HJELLE bearbeidet prøver og observasjoner fra Prins Karls Forland og St. Jonsfjorden i første del av året. Senere undersøkte han materiale samlet fra Antarktisekspedisjonen 1970/71, samt prøver og observasjoner samlet av F. R. ROOTS og A. REECE på Maudheimekspedisjonen 1949/52. Han gjorde ferdig til trykning en beskrivelse av H. U. Sverdrupfjellas geologi (Antarktis) samt en artikkel om geologien av Danskøya og Amsterdamøya (Svalbard). Sammen med Y. OHTA avsluttet han en beskrivelse over metamorfe facies i Hecla Hoek bergarter på Svalbard.

Y. OHTA bearbeidet materiale fra St. Jonsfjorden og utarbeidet et geologisk kart over dette området. Han gjorde ferdig til trykning to artikler om geologien omkring Smeerenburgfjorden og Magdalenefjorden på Spitsbergen.

D. WORSLEY gjorde ferdig bearbeidelse av materiale samlet fra øvre paleozoiske bergarter i Hinlopenstretet. Han fortsatte med undersøkelser av Bjørnøyas øvre paleozoiske lagrekke. Etter sommeren begynte han bearbeidelse av materiale samlet på Kong Karls Land.

M. B. EDWARDS (under Barentshavprosjektet) gjorde ferdig en undersøkelse av sandstein, samlet fra Spitsbergenbanken, og fortsatte med petrografiske studier av diverse sandstein-formasjoner på Svalbard.

Geofysikk

O. LIESTØL bearbeidet glasiologisk, meteorologisk og annet feltmateriale fra Svalbard og Norge. Han var også veileder for hovedfagsstudenter, holdt en forelesningsserie i glasiologi og var sensor for hovedfagsstudenter i limnologi og fysisk geografi.

V. HISDAL skrev ferdig et arbeid som behandler en ny metode til å fremstille fordelingen av skymengden, antall solskinnstimer og beslektede elementer. En undersøkelse hvor metoden anvendes på data fra de norske Ishavs-stasjonene er i gang. Sommerens observasjoner fra Svalbard av den kortbølgede strålings spektralfordeling og av intensiteten i forskjellige bølgebånd av den direkte solstråling, ble praktisk talt ferdig bearbeidet. Når et tilstrekkelig antall målinger av sistnevnte type foreligger, vil man ventelig få interessant informasjon om luftens partikkel- og vanndamp-innhold under forskjellige værsituasjoner i Svalbard-området.

T. VINJE utarbeidet isoversikter for den atlantiske sektor og beregnet driftshastigheter ut fra satellittbilder. Han fortsatte bearbeidelsen av målingene tatt i Antarktis i 1968–69 i forbindelse med studiet av friksjon og varmeutveksling mellom luft og snø. Videre arbeidet han med utredninger om havisproblemer i to komitéer og laget prosjektforslag i forbindelse med satellittmålinger.

O. ORHEIM bearbeidet glasiologisk feltmateriale fra Antarktis og Jan Mayen og utarbeidet planer for fremtidig norsk Antarktisaktivitet.

Biologi

T. LARSEN bearbeidet faunistisk observasjonsmateriale og registreringer av isbjørnhi på Kong Karls Land, for publisering. Store mengder data har gjort det nødvendig med et nytt registreringsskjema for faunaobservasjoner. De danner grunnlag for punching og databehandling. Et regnemaskinprogram for diskriminantanalyse på isbjørnkranier ble utarbeidet og testet. Elektroforesearbeidet på isbjørnserum ble avsluttet, og er klart for publisering. Våren 1973 bisto han Grønlands Zoogeografiske Undersøgelse med planlegging og gjennomføring av et isbjørnprosjekt på Grønland. Han var med på å utarbeide grunnlagsdokumentene for møtet i IUCN's Arctic Environment Specialist Group og for konferansen om en internasjonal avtale for beskyttelse av isbjørnen, som begge ble avviklet i Oslo i november 1973.

Cand.real. KARL HAGELUND har bistått med bearbeidelse av faunaregistreringene og et større ærfuglmateriale.

Biblioteket

I årets løp ble 250 titler registrert, herav 23 innkjøpte bøker, 95 av gammel bestand og 91 særtrykk.

Småtrykksamlingen har nu 5940 nummer. En del bøker er mottatt som gaver. Tilvekstliste ble utarbeidet. Tidsskriftene og seriene er ferdig klassifisert og katalogisert. Gjennomgåelse og revidering av småtrykksamlingen fortsatte.

Konsulent- og informasjonsvirksomhet

Instituttet har som i tidligere år vært konsultert om polar-spørsmål av norske myndigheter og av personer og institusjoner i inn- og utland.

T. GJELSVIK utarbeidet diverse redegjørelser for myndighetene, bl.a. i forbindelse med drøftelser av spørsmål vedrørende polarvitenskapelig samarbeid med andre land, i første rekke Canada og Sovjetsamveldet. Han var intervjuet en rekke ganger i pressen om polarspørsmål, særlig i forbindelse med den store Svalbardkonferansen som ble arrangert av Norske Sivilingeniørers Forening.

K. LUNDQUIST ga i egenskap av instituttets kontaktmann en rekke uttalelser til pressen.

Også andre av instituttets medarbeidere, bl.a. T. LARSEN, O. LIESTØL, O. ORHEIM, T. SIGGERUD og T. VINJE har, innen sine respektive fagområder, besvart henvendelser fra massemedia vedrørende instituttets arbeidsoppgaver og virksomhet i polarstrøkene.

Reiser, møte- og kursvirksomhet

T. GJELSVIK deltok i januar i en konferanse om arktiske problemer, som ble avholdt ved Queen's University, Canada. Han besøkte også Office of Polar Programs ved National Science Foundation, Washington, D.C. Videre deltok han som norsk representant i Hovedkomitéen for det europeiske Antarktisprogram, som avholdt møter i mars, juni og oktober, henholdsvis i Paris, Utrecht og Roma. Han besøkte i juni Tromsø Museum og overrakte som gave i anledning museets 100-års jubileum et russerkors fra Svalbard. I juli/august besøkte han det kanadisk-arktiske arkipel for å studere det forskningsarbeid som utføres i regi av The Polar Continental Shelf Project, og deltok deretter i en klimakonferanse ved Universitetet i Fairbanks, Alaska.

B. ARNESEN besøkte i februar Norges Sjøkartverk, Stavanger, og i mars Norges geologiske undersøkelse, Trondheim. Han deltok i «Kartdagene 1973», som ble arrangert i mars i Trondheim av Norges kartteknikse forbund. Videre deltok han i kurset «Papir og farge i offset», avholdt ved Statens teknologiske institutt i september.

V. HISDAL deltok i april i «9. Internationale Polartagung» i München.

A. HJELLE oppholdt seg i tiden 14/9—27/10 ved Geological Survey of Canada, for å studere geologiske prøver og observasjoner fra Maudheim-ekspedisjonen og bearbeide resultatene med henblikk på publisering.

T. LARSEN deltok i februar i et seminar på Høvringen, hvor han orienterte om isbjørnundersøkelsene i 1972. I mai deltok han i et kurs i økologisk genetikk ved Universitetet i Lund. Videre deltok han i september i den 11. kongress for viltbiologer i Stockholm og i oktober i World Wildlife Fund's internasjonale komitémøter og kongress i Bonn. Han besøkte i september også Uppsala Universitet for å studere elektroforeseteknikk og København Zoologiske Museum for å måle isbjørnkranier. Som oppnevnt norsk representant deltok han i oktober i IUCN's Survival Service Commission i Morges, Sveits, og ved forhandlingene i Oslo i november om en internasjonal isbjørnavtale.

O. LIESTØL deltok i juni i et symposium, som ble arrangert i Narssarssuak, Grønland, av den nordiske seksjon i International Glaciological Society.

REIDUNN LUND deltok i juni i 3rd Northern Libraries Colloquy, som ble avholdt i Cambridge, og besøkte ved samme anledning Scott Polar Research Institute, Cambridge.

REIDAR LUND deltok i kurs i personalledelse, som ble arrangert av Forbruker- og administrasjonsdepartementet på Klækken Turisthotell i mai.

E. NETELAND deltok i april i et kurs ved Norges Sjøkartverk, Stavanger, hvor bl.a. en ny utgave av «Hydrodist» elektroniske posisjonssystem ble demonstrert.

O. ORHEIM deltok i april/mai i årsmøte i International Glaciological Society og i et møte om Antarktis' glasiologi, arrangert av SCAR. Begge møtene ble holdt i Cambridge. I juni deltok han i et symposium som ble arrangert i Narssarssuak, Grønland, av den nordiske seksjon i International Glaciological Society. Videre møtte han som norsk representant i Hovedkomiteen for det europeiske Antarktisprogram, som avholdt møter i mars og oktober, henholdsvis i Paris og Roma. I tidsrommet 28/9—13/10 besøkte han vitenskapelige institusjoner i Leningrad og Moskva og deltok i et symposium i glasiologi. Besøket inngikk som et ledd i kulturavtalen mellom Norge og Sovjet.

T. SIGGERUD deltok i februar i et møte ved Jordskjelvstasjonen, Universitetet i Bergen, angående planlegging av videre vulkanovervåking på Jan Mayen.

I mars besøkte han en rekke vitenskapelige institusjoner på Island for å studere opplegget for vulkanvarsling og deltok også i en ekskursjon til Heimaey under vulkanutbruddet. Han deltok i mai i COSPAR-symposiet om «Remote Sensing», som ble avholdt i Konstanz. I november besøkte han Grønlands Geologiske Undersøgelse, København, og en del andre danske institusjoner som arbeider med drift av arktiske forskningsstasjoner på Grønland.

T. VINJE deltok som norsk representant i Informal Planning Meeting on POLEX, som ble arrangert i Leningrad i desember.

T. S. WINSNES deltok i mai i et symposium om olje og gass, som ble avholdt i Le Havre. På symposiet holdt han et foredrag om Svalbards geologi. I august deltok han i Third International Gondwana Symposium i Canberra, og i et møte i SCAR Working Group of Geology.

Forelesning og foredragsvirksomhet

T. GJELSVIK ga på Polarrådets første møte en bred oversikt over virksomheten i polarområdene. I april holdt han foredrag og deltok i den etterfølgende paneldiskusjon på Svalbardkonferansen 1973, som ble arrangert av Norske Sivilingeniørers Forening. Han holdt i desember, i likhet med tidligere år, forelesning ved Forsvarets Høgskole om norske interesser i Arktis og Antarktis, samt over et nytt tema «Mineralske råstoffressurser i polarområdene». I forbindelse med sin reise i Canada holdt han tre foredrag i Calgary og Ottawa om polarspørsmål og undersøkelser på den norske kontinentalsokkel.

T. LARSEN holdt to forelesninger ved Universitetet i Oslo om aldersbestemmelser og populasjonsdynamikk og tre forelesninger om økologi ved Distriktshøgskolen i Bodø. Han holdt et foredrag om marine økosystemer og havforurensninger på foreningen Nordens møte i februar og et foredrag om økologiske problemer i forbindelse med eksploatering av lagerressurser i arktiske strøk ved MAB-seminaret på Lillehammer i november. Videre kåserte han om isbjørn og isbjørnundersøkelser under World Wildlife Funds årsmøte og på et møte i Geofysisk Forening.

O. LIESTØL holdt i januar foredrag i Naturgeografen om «Nye glasiologiske forskningsresultater på Svalbard». På International Glaciological Society's symposium på Grønland i juni holdt han foredrag om «En ny teori for glacial surge».

Y. OHTA holdt foredrag om «Pre-cambrian structures between Kvinesdal and Mandal» på Norsk Geologisk Forenings vintermøte i Trondheim.

O. ORHEIM holdt i høstsemesteret forelesninger i glasiologi ved Universitetet i Bergen. På møte i Bergens Geologiske Klub holdt han foredrag om «Vulkanisme og Klimaforskning på Deception Island, Antarktis» og i Rogaland Akademi over emnet «Går vi imot en ny istid?»

T. SIGGERUD holdt foredrag om «Svalbards plass i det sirkumpolare område» på Svalbardseminaret i april. På Norsk Geologisk Forenings vintermøte i Trondheim holdt han foredrag om «Vulkanismen på Jan Mayen». Videre holdt han en forelesning ved Universitetet i Bergen om «Hyppighet og klassifisering av vulkanutbrudd på Jan Mayen». Han har også holdt en rekke foredrag i folkeadademier etc. med emner fra Svalbard og Jan Mayen.

T. VINJE holdt i mars foredrag i Oslo Geofysikeres Forening om «Satellitt-bilder i havisundersøkelser», og på Svalbardseminaret i april om «Vær og klimaforhold på Svalbard».

D. WORSLEY holdt et foredrag i Norsk Geologisk Forening om «Nyere undersøkelser av Bjørnøyas øvre paleozoiske lagrekke».

Publikasjoner

Skrifter

På grunn av vanskeligheter for det vanlige trykkeriet, måtte publiseringen av en rekke Skrifter utstå til 1974.

Årbok 1971

WORSLEY, DAVID: The Wilhelmøya Formation — a new lithostratigraphical unit from the Mesozoic of eastern Svalbard. 7—15.

HALVORSEN, ERIK: Demagnetization studies of the late Mesozoic dolerites from the Isfjorden area, Spitsbergen. 17—29.

HJELJORD, OLAV: Studier av revegetasjonsforløp i gamle traktorspor på Svalbard. 31—42.

ALLEN, K. C.: Further information on the Lower and Middle Devonian spores from Dickson Land, Spitsbergen. 43—54.

HORSFIELD, WILLIAM T.: Half-moon oolites from the Hecla Hoek of Nordenskiöld Land, Spitsbergen. 55—57.

GULLESTAD, NILS: Noen observasjoner av pattedyr og fugl i Kongsfjordområdet, Spitsbergen, 1970—1971. 59—66.

LIESTØL, OLAV: Glaciological work in 1971. 67—75.

HISDAL, VIDAR: The weather in Svalbard in 1971. 77—79.

VINJE, TORGNY E.: Sea ice and drift speed observations in 1971. 81—85.

NORDERHAUG, MAGNAR: Iakttagelser over dyrelivet på Svalbard 1971. 87—92.

GJELSVIK, TORE: Norsk Polarinstitutts virksomhet i 1971. 93—110.

— The activities of Norsk Polarinstitutt in 1971. 111—115.

— Main field work of scientific and economic interest carried out in Svalbard in 1971. 116—117.

Notiser:

GULLESTAD, NILS: Merking av røye (*Salvelinus alpinus* (L)) på Svalbard sommeren 1971. 119—120.

— Pukkellaks (*Oncorhynchus gorbuscha*) på Svalbard sommeren 1971. 121.

MUNKEBYE, ODD: First proof of breeding of Great skua (*Catharacta skua*) on Bjørnøya. 122.

LIESTØL, OLAV: Eskerdannelse foran Nathorstbreen i Van Keulenfjorden på Spitsbergen. 122—124.

Sjøkart

504 Fra Sørkapp til Bellsund (ny utgave)
510 Fra Kapp Linné med Isfjorden til Sorgfjorden (ny utgave)

Landkart

Svalbard 1:1 000 000 (ny utgave)
Dronning Maud Land 1:250 000:
L4 Schirmacheroasen
M4 Starheimtind

Instituttets medarbeidere har utenom instituttets serier publisert:

THOR LARSEN: Naturvernet på defensiven eller på offensiven? *Norsk Natur* **9** (3), 84–85.
— Survey of polar bear denning areas in Svalbard. *World Wildlife Fund Yearbook* 1972/73, 53–55.
— Isbjørnprosjektet. *IBP i Norge. Årsrapport 1972*, 398–407.

PER WEGGE, THOR LARSEN og JOHN KROG: Små radiosendere forteller om ville dyrs liv og bevegelser. *Forskningsnytt* **18** (6), 25–29.

OLAV LIESTØL: Isbreer. Artikkel i *Familieboka*, Aschehoug Forlag, Oslo 1973.

YOSHIHIDE OHTA: Geology of Nepal Himalayas. Saikon Pub. Co. Ltd., Tokyo. P. 289. Editor in chief.

THOR SIGGERUD (sammen med A. G. SYLVESTER, T. NAVRESTAD, J. MATHISEN og O. HAGEN): Surveillance of Volcanic Activity in Iceland, as illustrated by the Heimaey 1973 eruption. Seismological Observatory, Universitetet i Bergen.

TORGNY VINJE: On wind and temperature profiles above an Antarctic ice shelf. *WMO's serie Technical Note*, **129**.

Forskningsstasjonen på Svalbard (Kap. 340)

AV THOR SIGGERUD

Forskningsstasjonen har vært i drift hele året. Aktiviteten har hovedsakelig vært geofysiske registreringer. Det foregår nå forholdsvis omfattende rutinemessige registreringer. En del av dataene går inn til internasjonale datasentraler.

Stasjonen disponerer to bygninger leiet av Kings Bay Kull Comp. A/S, en i selve Ny-Ålesund og en inne ved fjellfoten. I sistnevnte bygning er den seismiske stasjonen innredet. Det har til dels vært vanskelig å få tilfredsstillende forbindelse med denne stasjonen til faste tider, spesielt under ugunstige værforhold i mørketiden.

Innkvartering og bespisning av det faste personell og gjestende forskere har skjedd i samarbeid med NTNF som driver Kongsfjord Telemetristasjon. Kapasiteten har spesielt i sommersesongen vært for liten, slik at innkvartering til dels har måttet bli forholdsvis primitiv. NTNF har som tidligere sørget for sentraloppvarming, vann- og elektrisitetsforsyning til bygningene.

Frem til september var cand.mag. BJØRN WOLD vitenskapelig assistent ved stasjonen. Cand.mag. KJELL REPP overtok hans stilling etter en overlappingsperiode på ca. 1 måned.

Elektrotekniker ved stasjonen har vært JENS ANGARD. I perioder har HALVARD BOHOLM og FRED KLOKKERVOLD vikariert. Teknikere ved Kongsfjord Telemetristasjon har etter behov vært engasjert for enkelte oppdrag, og personell fra NTNF's verksteder har utført arbeid av forskjellig slag ved Forskningsstasjonen.

En rekke norske forskningsinstitusjoner og forskere har benyttet seg av stasjonens muligheter for ved hjelp av registrerende instrumenter å samle inn data på disse høye breddegrader.

Følgende undersøkelser har vært i gang i 1973:

Registrering av energibalansen av kort- og langbølget stråling.

Spektrale intensitetsmålinger av sol- og himmelstråling juli—august.

Massebalansemålinger av breer, dvs den årlige akkumulasjon og avsmeltning.

Tidevannsregistreringer gjennom hele året.

Kontinuerlig mottaking av VLF-signaler (foreløbig slutt fra sommeren av).

H F absorbsjonsmålinger ved riometre hele året.
Elektrontetthetsmålinger av F-lag november —mars.
Fotometrering av pulserende nordlys oktober —mars.
Natthimmelfotografering med «all-sky-kamera» oktober —mars.
Registrering av jordmagnetismen hele året.
Seismiske registreringer av 6 komponenter hele året.
Biologiske observasjoner foretatt hele året, men særlig april—mai.
Sommeren 1973 ble det montert utstyr for luftforurensningsmålinger ved filtre. Utstyret ble montert i luftskipsmasten ca. 10 m over bakken.

I tiden mars—august hadde stasjonen offisielle besøk bl.a. av statsråd P. KOREN og formann i Polarrådet, fylkesmann L. LEIRO, statsråd H. GITMARK, dr. E. SINGER fra Geografisk institutt, Moskva, og sysselmann F. BEICHMANN sammen med medlemmer av det interdepartementale polarutvalg. Stasjonen hadde også en rekke besøk, både av utlendinger og nordmenn, som ba om hjelp og veiledning av forskjellig slag. Særlig var det stor pågang for å få båttransporter.

Ti forskere, til dels med assistenter, har benyttet stasjonen, enten for utprøving og kontroll av instrumenter eller som base under feltarbeid i området. Oppholdene, som for de flestes vedkommende fant sted i sommersesongen, varierte fra to dager til to måneder.

Den planlagte nedleggelse av Kongsfjord Telemetristasjon har medført en del usikkerhet med hensyn til plassering og fremtidig drift av Forskningsstasjonen. Anskaffelser og utbedringer ved stasjonen har derfor vært holdt på et lavmål.

The activities of Norsk Polarinstitutt in 1973

Extract of the annual report

By TORE GJELSVIK

Norsk Polarinstitutt had 34 permanent positions in 1973. A new position for a quaternary geologist had not been filled by the end of the year. Six employees were in addition engaged on short-term contracts.

Field work

NORWAY

Glaciology

The studies were led by O. LIESTØL, who conducted routine glacier mass balance measurements at Storbreen and Hardangerjøkulen. A. TVEDE continued mass balance measurements at Folgefonni.

Frontal position variations were measured at 11 glaciers, two off Folgefonni, two in Jotunheimen, four by Jostedalsbreen, two in Møre, and one at Svartisen.

SVALBARD

In March/April a four-man expedition was sent to Kong Karls Land to study polar bear dens.

The summer expedition was organized and led by T. SIGGERUD. Altogether 33 persons participated, exclusive of the crews of ships and helicopters. This smaller number than usual was a result of the escalating costs of the logistics.

The expedition conducted hydrographic, topographic and geologic work, mostly in eastern and southeastern parts of Svalbard. In addition were conducted hydrographic survey in Isfjorden, geophysical investigations in Ny-Ålesund, and geologic studies at Bjørnøya, Oscar II Land, and Sørkapp.

Two biologists from the University of Bergen were assisted by the expedition and worked in the area south of Isfjorden.

The main part of the expedition sailed on M/S "Norvarg" with Captain O. JOHANNESEN and a crew of 13 men from Bodø on 18 July. The vessel went to Hammerfest on 16 August and fetched fuel for the helicopters. The expedition disembarked in Bodø on 6 September.

Two Bell 47 J helicopters with crew were rented from Helikopter Service A/S for transport between M/S "Norvarg" and the field localities.

"Norvarg" first put ashore geologist Y. Ohta in Forlandsundet and fetched the helicopters that were transported by cargo ship to Longyearbyen. It then continued to Storfjorden where topographic survey was conducted. Further such work was done at Barentsøya and Edgeøya where geologist T. S. Winsnes also worked. In addition the helicopters flew around Barentsøya for the Environmental Inspector for Spitsbergen. Topographic work was completed at Kong Karls Land, where also geologist D. Worsley was placed. From Kong Karls Land "Norvarg" went north of Spitsbergen via Ny-Ålesund to Longyearbyen, where the helicopters were put ashore for return to Norway by cargo ship. On "Norvarg" 's return to Norway, geologist M. Edwards was picked up at Sørkapp. Biologic observations, partly by use of helicopters and small boats were conducted during the whole expedition.

Various experiments with radios, antennas, and schedules were carried out in the course of the summer with a view to improving the sometimes difficult communication at these high latitudes. Several huts in eastern and northern regions were inspected and repaired.

R/C "Sjøfareren" with Captain M. Hansen and a six man crew was used for hydrographic surveying in Storfjorden.

The weather conditions were average, but strong winds in clear weather situations hindered the flights.

The ice situation was abnormal, with little ice during most of the summer. This led to unexpected problems for the expedition, in that high swells several times hindered the ship board helicopter operations.

Hydrography

H. Hornbæk, assisted by S. Utheim and I. Fjeld, used the sounding boat "Svalis" from 18 July to 5 september in Tempelfjorden and in Forlandsundet south of Forlandsrevet.

The other hydrographic survey from 16 July to 8 September with R/C "Sjøfareren" was led by J. H. Christiansen. E. Neteland looked after the HI-FIX-system and other electronic equipment.

HI-FIX slave stations on Lurøya and Hopen were operated by two assistants at each place.

It was decided that the circumstances of favourable ice situations and a ship with very good manoevring ability warranted an attempt to complete the soundings of the very difficult area between Tusenøyane. The soundings were conducted from 1 August to 4 September. Altogether 5200 nautical miles were sounded along lines about 800 m apart.

Geodesy – topography

O. Steine (leader), J. Bjørke, J. Sundsby, D. Bjørkedal, and Y. Johansen carried out the geodetic and topographic field work. The main work was to extend the triangulation net and measure in ground control points for mapping in the scale of 1 : 100,000. Measurements were done at the northern and western side of Agardhbukta (Spitsbergen), Barentsøya, main part of Edgeøya and Kong Karls Land. The HI-FIX stations at Ryke Yseøyane and on Svenskøya were joined to the triangulation network. Transportation was by helicopter.

Geology

Four geologic parties worked on Svalbard. Y. OHTA worked from 21 July to 2 September in Oscar II Land south of St. Jonsfjorden, mainly mapping and investigating Hecla Hoek rocks and carboniferous sediments.

T. WINSNES worked from 24 July to 4 September at Barentsøya and Edgeøya, doing mapping and studies, especially on sections from Lower Trias.

D. WORSLEY and M. EDWARDS investigated from 19 July to 17 August the Upper Palaeozoic sections of Bjørnøya. M. EDWARDS then moved to Sørkapp-land, where he worked on Mesozoic sediments until 4 September. D. WORSELY moved from Bjørnøya to Edgeøya and later to Svenskøya and Kongsøya, where he from 21 August to 31 August measured detailed geologic profiles.

Geophysics

Measurements of mass balance of glaciers around Ny-Ålesund continued during 1973. Extensive, detailed studies of the glacio-hydrologic conditions in a representative basin were in addition initiated in 1973. Most of the work has been done by B. WOLD and K. REPP.

V. HISDAL worked at The Research Station in Ny-Ålesund from 6 July to 3 August and began a series of measurements of direct sun radiation in three wave length bands. The spectral distribution of the global and sky radiation was recorded whenever weather conditions permitted. Precipitation samples were collected for later analysis.

T. VINJE worked also in Ny-Ålesund from 20 July to 20 August. He calibrated the radiation instruments both in short- and long-wave region and mounted a new albedometer. At the end of 1973 a multipoint recorder was installed to assure continuity in the registrations. The radiation instrumentation at the Research Station is now considered adequate for the registration of all main radiation components of climatic interest.

JAN MAYEN

O. ORHEIM conducted mass balance studies at Sørbreen, Jan Mayen, from 16 to 23 August and gave instructions for further observations.

Preparation of data

Hydrography

Editing work was done on new chart 522, and on new editions of charts 502, 505, and 509. Preparations were made for reprinting charts 504 and 510.

In connection with long-term leasing of M/S "Olav Scheel" the hydrographers in cooperation with engineer T. Søndenaa, have prepared specifications for necessary rebuilding of the ship. Estimates and orders have been made for new electronic equipment for the vessel.

Geodesy – topography

Adjustments of the geodetic net at Svalbard have continued. The results were available of the 1971 doppler observations. The work on place names on Svalbard continues, and a new edition of the Svalbard 1:1,000,000 map has been completed. Maps B4 Reinsdyrflya, B5 Woodfjorden, and part of C8 Billefjorden have been constructed.

The section continued work on place names and various maps of Dronning Maud Land. L4 Schirmacheroasen and M4 Starheimtind in the series Dronning Maud Land 1:250,000 were completed. Several other maps in the same series are in preparation, of these N5 Forposten and N6 Sarkofagen are ready for proof reading.

Geology

H. Major continued coal petrographic studies of samples from mines 3, 4 and 7 in Longyearbyen. He delivered reports on the coals at Svalbard to the World Energy Conference 1973.

T. S. Winsnes prepared a review of Svalbard's geology for a symposium on oil and gas in Le Havre in May. He conducted photogeologic studies of Edgeøya and Barentsøya in preparation for the summer's expedition and later he investigated fossil samples collected during the expedition.

A. Hjelle worked on samples and observations from Prins Karls Forland and St.Jonsfjorden, and on material collected on the Norwegian Antarctic Expedition 1970/71. In agreement with Dr. E. F. Roots, he also analysed samples and observations collected by F. R. Roots and A. Reece on the Norwegian-British-Swedish Maudheim Expedition 1949–52. He completed a manuscript on the geology of H.U. Sverdrupfjella (Antarctica) and an article on the geology of Danskøya and Amsterdamøya (Svalbard). Together with Y. Ohta he completed a description of the metamorphic facies in the Hecla Hoek rocks.

Y. Ohta studied data from St. Jonsfjorden and prepared a geologic map of this region. He completed two articles on the geology around Smeerenburgfjorden and Magdalenefjorden in Spitsbergen.

D. Worsley completed analysis of data on the Upper Palaeozoic rocks in Hinlopenstretet. He continued studies of Bjørnøya's Upper Palaeozoic section. After the field season he started work on the samples collected on Kong Karls Land.

M. B. Edwards completed studies of sandstone collected at Spitsbergenbanken, and continued petrographic studies of various sandstone formations at Svalbard.

Geophysics

O. LIESTØL prepared glaciologic, meteorologic and other field data from Svalbard and Norway. He was also adviser for graduate students and held a lecture series in glaciology at the University of Oslo.

V. HISDAL completed a manuscript on a new method to show distribution of cloud quantity, sunshine hours, and related elements. The method is being tested on data from the Norwegian stations in the Arctic. The summer's observations in Spitsbergen on the spectral distribution of the short-wave radiation and the intensity at different wave lengths were analysed. It is anticipated that the later observations will give interesting information on the atmospheric particle and water vapour content under different weather situations.

T. VINJE prepared sea ice charts for the Atlantic sector and computed drift velocities using satellite photographs. He continued analysis of measurements from Camp Norway II (Antarctica) in connection with studies of friction and heat exchange between air and snow. He also prepared reviews of sea ice problems and future research.

O. ORHEIM analysed glaciologic data from Antarctica and Jan Mayen, and prepared plans for future Norwegian activity in Antarctica.

Biology

T. LARSEN prepared for publication faunal observations, data and registrations of polar bear dens at Kong Karls Land. Large quantities of data have necessitated a new registration form for faunal observations, which simplifies data transferral for computer treatment. A computer programme for polar bear crania data was developed and tested. Electrophoresis work on polar bear serum was completed. In spring 1973 he assisted Grønlands Zoogeografiske Undersøgelse with the planning and conducting of a polar bear project on Greenland. He participated in preparing documentation for the meeting of IUCN's Arctic Environment Specialist Group and for the conference on International Agreement for Protection of the Polar Bear, which both were held in Oslo in November 1973.

The Research Station at Ny-Ålesund

The research station was operated the whole year, and has been used mainly for geophysical studies. A fairly extensive programme of routine registrations is now in operation, with some of the data being transmitted to international data centers.

The station uses two buildings rented from Kings Bay Kull Comp. A/S, one in Ny-Ålesund proper and one by the mountain side. The seismic station is installed in the latter.

B. WOLD was scientist at the station until September, when K. REPP took over.

J. ANGARD is Electronic technician at the station. At times H. BOHOLM and F. KLOKKERVOLD have substituted.

Several Norwegian research institutions and scientists have made use of the opportunities at the station to register data at high latitudes.

The following studies have taken place in 1973:

Registration on energy balance of short- and long-wave radiation.
Spectral intensity measurement of sun and sky radiation (July–August).
Measurements of mass balances of glaciers.
Tidal registrations.
Continuous receiving of VLF-signals (first half of the year).
HF absorbtion measurements by rhiometers.
Measurement of electronic density of F-layer (November–March).
Photometering of pulsating aurora borealis (October–March).
Night sky photography by "all-sky-camera" (October–March).
Registration of earth magnetism.
Seismic registration of 6 components.
Biologic observations were made throughout the year, but especially in April–May.

Equipment for filter measurements of air pollution were installed in summer 1973 at an above-surface level of 10 m.

Ten scientists, plus assistants, have used the station for testing and control of instruments or as a base for field work. The visits, mostly during the summer, varied in length from two days to two months.

Main field work of scientific and economic interest carried out in Svalbard in 1973

By Tore Gjelsvik

Nationality	Institution or company (residence) Name of expedition	Name(s) of leader(s) Number of participants	Area of investigation Period	Work
Norwegian	Norsk Polarinstitutt	Thor Siggerud 36 (+ transport crew, 2 ships and 2 helicopters)	Svalbard and Barents Sea June, July, August	Hydrography, topography, geology, geophysics and biology. See pp. 00–00.
	Norsk Polar Navigasjon A/S	Per Kværnmo 11	Kiærdammane Brøggerhalvøya April 10–November 20	Diamond drilling.
	Norske Fina A/S	141	Hopen Summer season	Moving of rig from Edgeøya, drilling, oil exploration.
	University of Bergen	Yngvar Gjessing 2	Blomstrandhalvøya July 17–Mid-August	Zoology.
	Zoological Museum, Bergen	Einar Alendal 2	Area between Isfjorden and Van Mijenfjorden	Counting reindeer and musks.
	University of Trondheim	Ingvar Brattbakk 4	Kapp Wijk June 21–August 25	Ecology.
British	Cambridge Spitsbergen Expedition 1973	W. B. Harland 12	West coast of Hopen, Ny-Ålesund, Berzeliusdalen, Kapp Linné July 5–Mid-September	Geology.
	The Wildfowl Trust, Gloucester	E. E. Jackson 6–7	Area around Hornsund July 15–August 4	Ornithology.
	Universities of East Anglia and Nottingham	M. A. Paul 5	Around Kongsfjorden and Engelskbukta June 21–September	Glaciology.
French	Expédition Française d'Ornithologie Polaire	Chr. Kempf 9	Area around Ny-Ålesund and Longyearbyen June, July, August	Ornithology.

Nationality	Institution or company (residence) Name of expedition	Name(s) of leader(s) Number of participants	Area of investigation Period	Work
German	Zoolog. Inst. Friedrich-Alexander-Universität, Erlangen	H. Remmert 4	Isfjord area July 1–August 4	Zoology, Ornithology/ Permafrost studies.
	Geographisches Institut Frankfurt/Main	A. Semmel 5	Eskerdalen area Isfjord area Mid-July–August 25	Permafrost studies, Zoology.
Dutch	Not known	P. C. Gondswaard 2	Kapp Linné Mid-July–	Ornithology.
	Not known	O. Plantema 2	Kongsfjord area July	Ornithology.
Polish	University of Wroclaw	S. Baranowski 10	Hornsund June 15–September 20	Glaciology, geomorphology.
Soviet	Sevmorgeo	Viltner 15–20	Bjørnøya, Hopen, Sørkapp June 15–Mid-August	Geophysics.
	Sevmorgeo	D. V. Semevskij 15 (+ transport crew)	Raudfjorden, Wijdefjorden, Isfjorden July 10–September 25	Geology.
Swedish	University of Lund	Berit Olsson 3	Kapp Linné June 29–July 16	Ornithology.
	University of Uppsala	Stig Larsson 2	July 26–Mid-August	Quaternary studies.

Notiser

The Morphology and Evolution of an Esker in Spitsbergen.

Abstract. — The morphology, sediments and sedimentary structures of an emerging esker are described and their evolution discussed.

Introduction. — Battyebreen is a moderately sized valley glacier, 20 km long and 69 km squared in area, at the head of Dicksondalen, James I Land, Spitsbergen. The glacier possesses many morphological characteristics that are diagnostic of surging glaciers, such as moraine loops, truncated tributary moraines and "pushed sediments".

The active ice is now well within the limits of the last surge, allowing the release of entrained debris in several morphologically and sedimentologically distinct zones of the stagnant lower 2 km of the glacier (Fig. 1).

The innermost zone comprises a shallow supraglacial lake, into which a flat-topped esker of distinctly bedded sand and gravel extends from a concealed source in the active glacier ice. In 1973, the feature was 800 m long, between 12 and 20 m wide, with an average height of 4.7 m. The relatively rapid emergence of the esker from an englacial tunnel in clean ice debris-free has been traced from air photographs taken in 1966 and 1969; its rate of emergence is now

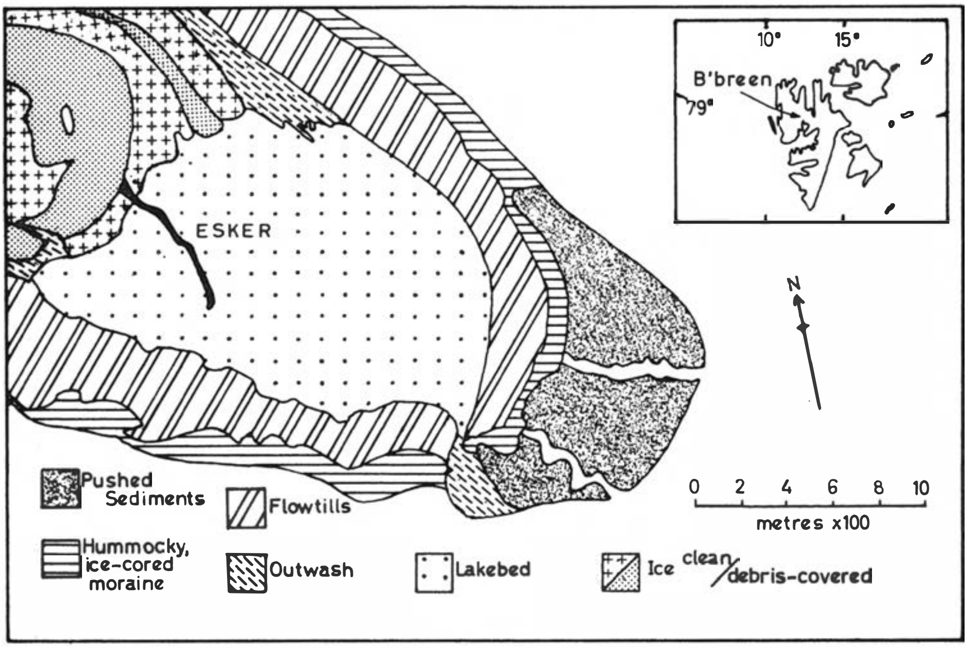


Fig. 1. *Map of the pro-glacial zones of Battyebreen, Spitsbergen. The inset shows the location of Battyebreen.*

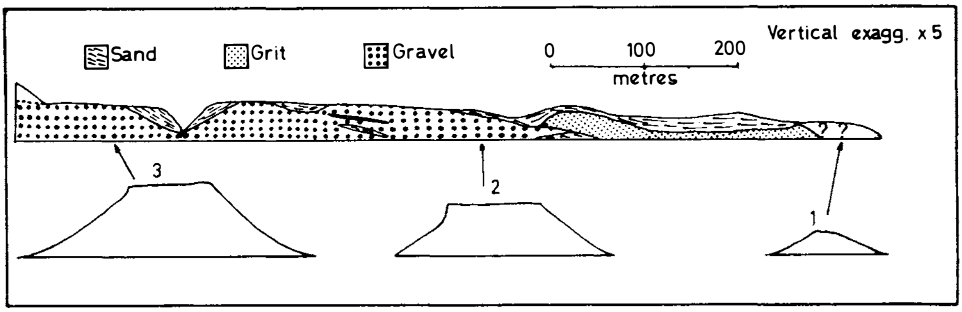


Fig. 2. *Long profile and section of Battyebreen esker. Cross profiles of the esker are shown below.*

certain to slow down however, because a 50 m high ridge of debris-covered ice must melt to reveal any further extension of the feature. The plan form of the esker has remained constant since 1966 but no ground control is available to see whether the elevation of each section has changed through time.

Morphology of the esker.

(a) *Plan.* The plan form is not sinuous but comprises straight sections up to 200 m in length connected by abrupt bends and corners.

(b) *Long profile.* The long profile slopes away from the ice front at a gradient of 1:32, but it shows greater microrelief than this.

(c) *Cross profiles.* These show a change in character along the feature and apparently vary with: (i) length of exposure, (ii) parent material, (iii) height and position of beds, (iv) amount of undercutting at the base.

Profile 1 (Fig. 2) is affected by length of exposure; there is no discernible bedding and the whole profile is totally degraded. Elsewhere, factors (ii), (iii) and (iv) influence the form of the profile to varying degrees. Undercutting is particularly evident on the south-western face of the esker where a powerful melt stream washes against it. Sands predominate in the upper sections (Fig. 3) where free faces up to 2 m high occur (Fig. 2, profile 2). The unconsolidated slumped material is at its angle of rest along this section. Near the active glacier ice, the esker is capped with coarse gravel which maintains only short (0.3 m) vertical faces with long lower-angle clitter slopes (Fig. 2, profile 3).

Sediments and Sedimentary Structure. — As the esker presently melts out from an englacial position, an internal ice core at least 3 m high is apparent. Relict glacier ice is visible in a section at the proximal end of the esker and, since the lower sand beds are permanently saturated, all along the feature, with sapping and slumping continually occurring, a water supply most likely derived from an ice core is suggested. The present form and sedimentary structure of the feature are therefore only temporary and will change as the ice melts out. Thus they can only provide evidence of the original depositional environment in their present unmodified form.

The proportions of sand, grit and gravel in the esker change significantly along its length. Gravels decrease in volume away from the active ice front and occupy successively lower positions in the feature. Sands, on the other hand, increase to an estimated 70 % of the total volume of the esker near its terminus.

The degrees of sorting of individual facies do not vary systematically longitudinally, but there is a large range of values of "degree of sorting" in all

Fig. 3. *Panorama of the Battyebreen esker.*

sections. On a scale of 0–100 %, where zero is least sorted and 100 % represents all the sample falling into one size class (SHARP and FAN 1963), the esker sediments have a range of 23 to 71 %.

Bedding structures are sharply defined with dips of 7–10 degrees towards the distal tip, and abrupt changes occur between fine rhythmic or current-bedded sands and ill-sorted beds of large gravels.

Conclusions. — (1) The esker was deposited immediately following the last surge of Battyebreen.

(2) The esker has a slowly melting ice core, along at least part of its length.

(3) Sediments and sedimentary structure show evidence of a volume of englacial water capable of both transporting large gravels and depositing current-bedded sands in close proximity.

Acknowledgements. — The writer is grateful for the help and encouragement of Professor K. WALTON and Dr. C. M. CLAPPERTON, Department of Geography, University of Aberdeen, and acknowledges a N.E.R.C. training award for support in the field.

References

SHARP, W. E. and P. F. FAN, 1963: A sorting Index. *Journal of Geology*, **71**, 76–83.
SZUPRYCZINSKI, J., 1965: Eskers and Kames in the Spitsbergen Area. *Geographia Polonica*, **6**, 127–140.

David G. Croot B. A.
University of Aberdeen
Department of Geography
Old Aberdeen, AB9 2UF
Scotland

Dating of the Bison find from Siberia
A supplement

In Norsk Polarinstitutt Årbok 1970 — a find of Bison bones from Ajon Island in North-Eastern Siberia is mentioned. During wintering 1919–20, Amundsen found several bones of the skeleton of a Bison laid bare in the sediments of the island.

In the paper published on the find (MØHL 1970, 178–190) the supposition was set forth that these bones — which could reasonably be referred to a single individual — derived from a bison belonging to one of the most recent Siberian populations, which in these northern regions did not become extinct until about the middle of Holocene (FLEROW 1967, 278).

In order to obtain, if possible, a more exact dating, one of the bones from the find (left ulna. A 34227) (MØHL 1970, Plate I no. 4) with permission from Prof. A. HEINTZ, Palaeontologisk Museum, Oslo — was taken out for C-14 dating in Copenhagen.

H. TAUBER informed me (verbal communication) that the sample (K-2076) showed an age of $33220 {}^{+2070}_{\div 1610}$ before 1950, or about 31270 B.C. (The asymmetrical uncertainty is due to the high age of the sample which, however, can be determined to be more than 30 000 years. TAUBER). In view of this age, which is considerably higher than supposed, the Ajon Bison can no longer be regarded as one of the last representatives of the extinct North-Eastern Siberian population.

This agrees with the primary impression of the morphology of the bones, according to which it was stated for the metacarpus: "it is true that this bone is short, but its relative measurements, notably the breadth of the middle of the bone in relation to the length, indicate a vigorous animal which had favourable food conditions during growth." (MØHL 1970, 188).

Favourable habitats did exist throughout very large areas, especially in the north-eastern part of Siberia during the last Glaciation, the Würm-Glaciation (FRENZEL 1968, Map Fig. 5), where Ajon, due to the lower sea level, was included in this northern area. As mentioned by Frenzel, this area was "tundra with steppe elements and arctic steppe vegetation", an ideal biotope to bison and other large Herbivores (Mammoth, Woolly Rhino a.o.).

These optimal life conditions during the final phase of melting of this period were changed to such a degree, on account of the climatic conditions, that the above mentioned species gradually became extinct in the Siberian region (FLEROW 1967, 278; VERESHCHAGIN 1974, 11).

The Ajon Bison thus lived in the later part of this period with favourable conditions to Herbivores, during the Würm-Glaciation, and possibly, via Beringia, supplied elements which are reflected in the recent North-American (Canadian) populations.

РЕЗЮМЕ

Автор описал в 1970 г. остатки бизона, найденные в 1919–20 г. на острове Айоне (С.-В. Сибирь) экспедицией Р. Амундсена. Возраст этого бизона, определенный теперь при помощи С-14 в Копенгагене, оказался $33220 {}^{+2070}_{-1610}$ лет (до 1950 г.) и значит значительно выше, чем автор предполагал раньше.

Таким образом бизон с Айона не может считаться представителем последних бизонов

Сибири. Он жил в последней части довольно благоприятного периода вюрмского оледенения с сравнительно богатой степной растительностью. Через Берингию этот тип бизона, быть может, повлиял и на строение современных бизонов С. Америки (Канады).

References

FLEROW, C. C., 1967: On the Origin of the Mammalian Fauna of Canada. In: (D. M. HOPKINS) *The Bering Land Bridge*, 271–280. Stanford. Calif., U.S.A.

FRENZEL, B., 1968: *Grundzüge der Pleistozänen Vegetationsgeschichte Nord-Eurasiens.* 637–649. I. Wiesbaden.

MØHL, U., 1970: Bones of Bison from Ajon Island. Finds from Amundsen's Expedition in 1918–20. 178–190. *Norsk Polarinstitutt Årbok* 1970. Oslo.

VERESHCHAGIN, N. K., 1974: The Mammoth "Cemeteries" of North-East Siberia. 3–12. *Polar Record* **17** (106). Cambridge.

Ulrik Møhl
Zool. Mus. kvartærzool. Undersøgelser
Universitetsparken 15
2100 København Ø.

A.s John Griegs Boktrykkeri, Bergen