The chemical composition of the precipitation and surface water and its relation to evaporation on Björnöya Island, Norway

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ABSTRACT

Surface water and precipitation samples were taken from Bjørnøya Island and analysed for various constituents. The ion contents of the waters are related to the different kinds of rock found in this area. An ettempt has been made to calculate the evaporation from the concentrations of different ions. An approximate evaporation rate of 72 % has been found, which corresponds to meteorological estimations.

Introduction

The Department of Geography at Stockholm University has carried out a series of expeditions in recent years, in order to study the extent of the uplift in the Baltic region after the Ice Age. One of the areas concerned is Björnöya Island. In 1965 an expedition was organized to study the possibilities of confirming any uplift that may have taken place. One of the most notable methods of doing this is to study lake-sediment cores. By C^{14}-dating the borderline between lacustrine and marine diatomaceous sediments, from lakes at different altitudes, it is possible to determine the land elevation. Water samples from lakes, rivers and snow were taken and analysed for their various constituents in connection with core-sampling from the bottoms of lakes, the idea being that this would add more information regarding the chemical release of different ions from rocks, loose deposits and the chemical transport and balance in clouds, precipitation and natural waters, due to the special conditions on Björnöya.

Geographical conditions

Björnöya Island is situated between Norway and Spitsbergen (latitude 74°30′ N and longitude 19° E). The distance to northern Norway is 445 km and southern Spitsbergen 220 km.

A. Topography

Björnöya is naturally divided into a north-western lowland area and a southern and eastern mountain range (see Fig. 1).

The lowland is extremely flat at some 30–40 m above sea-level. The edge of the lowland mainly consists of a cliff 20–30 m high, which usually makes access from the sea impossible. The plateau is very rich in lakes, which are often situated in shallow declines or formed in the softer parts of the rocks, or along faults. The lowland is about 110 km² in area and has more than 600 lakes. Water covers about 12 % of the total area. Most of the lakes are very shallow. Below 50 m a.s.l. there are only about 10 with a depth of more than 3 m.

The high western and southern parts of the island can briefly be described as a plateau mountain, bifurcated by a deep valley in the higher southern part running N.–S., turning N.W.–S.E. with the River Russeelve and debouching on the south-eastern coast. The mountainous parts are not very rich in lakes, but where lakes exist, they are usually deeper than in the lowlands. Only one lake (Ellasjöen) has a depth of more than 10 m; it is about 30 m deep over a large area.

B. Geology

The rocks of Björnöya originate from lower Ordovician to Upper Carboniferous or Triassic depositions of shales and sandstones. The order

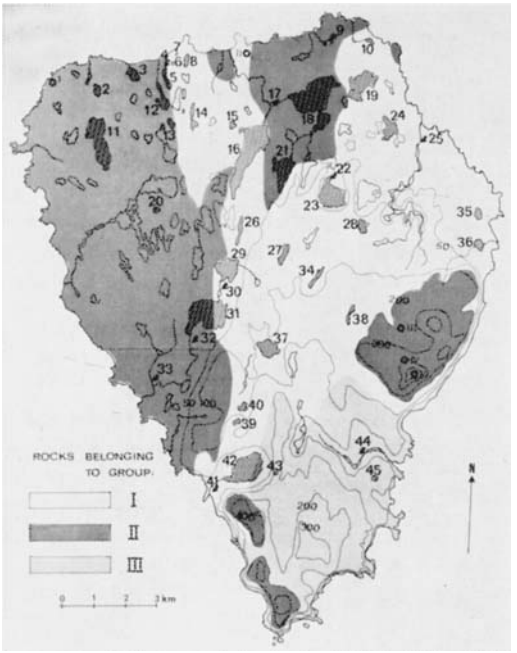

Fig. 1. Björnöya. Map based on the geological map of Björnöya by Horn & Orvin. ☽, Sample from running water; ✪, sample from snow or precipitation. The remaining numbers indicate samples from lakes.

of the strata is given in Table 1 and Fig. 1 (Horn & Orvin, 1928). The sandstones and limestones are fairly homogeneous, whereas the dolomites are more complicated, with veins of barayth, galena and blende in the older series.

It is clear from Fig. 1 that the rocks are of a very different character. To facilitate the further treatment, the rocks have been grouped in three appropriate classes, which are shown in Table 1 and Fig. 1.

The loose deposits consist mostly of crumbled rocks. Pure moraine is not found. Nevertheless, it is not uncommon to find heaps of ice-transported stone material. Some of the weaker sandstones and limestones have weathered to a finer material and at a few places something approaching a thin layer of soil has been found.

The shallow lakes on Björnöya usually contain no sediments; such sediments were hardly ever found in lakes less than 3 m deep.

The river beds consist mostly of a very coarse material; sediment occurs very rarely.

C. Climatology

The climate of Björnöya is markedly maritime, because of the position of the island. The Gulf Stream runs to the S. and W. of the island and a northern polar stream runs to the E. Most of the time, therefore, the island is enveloped in fog; the weather, on the whole, is dull and dreary.

A meteorological station has been in operation of Björnöya for about 50 years, except during World War II. The most recent meteorological observations are from the periods 1931–40 and 1951–60. The precipitation and temperature figures are given in Figs. 2 and 3.

The relative humidity is rather high, with values varying between 85 % in February and 92 % in July. The reports on the relative humidity in 1963 and 1964 seem to be inaccurate; according to the *Norsk Meteorologisk Årsbok*, "the hygrometer was out of action for long periods during 1964 as well". The average cloud cover is as high as 85 %.

D. Permafrost

The ground is frozen to a depth of about 65 m. Some 0.75 m of the surface thaws in summer. Lake and river beds have more extensive thawed zones.

Technical details

Samples of lake and river waters were taken during the period May 18 to June 6. The wather during this period was characterized by winds from the N.E. and the mean temperature recorded varied between −8.5° and 0.0°C, with just one day above freezing-point, the maximum temperature being 1.9°C. The thaw during the period was of little importance and the insolation caused little recrystallisation in lake ice and in daytime thawing in the upper 10 cm in patterned ground. No warm run-off water or melting of shore ice around the fringes could be observed.

Variations in the chemical composition of lake and river waters, due to melting, were thus of little importance during the period.

The surface run-off seemed to be equal to the mean water flow, according to observations of vegetation in river beds and watermarks on rocks.

A Ruttner sampler was used in the lakes;

Table 1. *The geological formations on Björnöya*

System	Series	Formation	Sign	Thickness, m	Description
Triassic	Carnian		I	190	Myophoria sandstone
Carboniferous	Upper	Spirifer limestone	II	120	Highly fossiliferous
		Cora limestone		50	Limestones and sandstones
		Fusulina limestone		75	Dark limestone
	Middle	Yellow sandstone		150	Yellow calcareous sandstone
		Ambigua limestone		175	Grey limestone
		Red conglomerate	I	100	Chiefly red conglomerate sandstone
	Lower (culm)	Ursa sands		150	White, grey sandstone, thin coal seam near top
Devonian	Upper	Unconformity		230	Sandstone, shales, conglomerate Three coal seams
Ordivician	Middle	Hecla Hoek: Tetradium	III	240	Black limestones with Tetradium
	Lower	Later dolomite		400	Grey dolomites
	?	Slate-Quartzite		175	Green and red slates, quartzitic sandstones
Cambrian ?	Ozarkian ?	Earlier dolomites			Grey dolomites, partly oolitic

when possible, water was taken 0.7 m below the ice. The ice was usually between 1.2 and 1.4 m thick. When it was impossible to find enough free water under the ice, due to the shallowness of the lakes, samples were taken from the outflow. River samples were taken in the middle of the stream. A few samples of snow were taken from different altitudes and one sample of precipitation (on June 5, the only day with measurable rain). The snow samples were cut from vertical columns (ca $50 \times 10 \times 10$ cm) to avoid irregularities in the snow layers.

The analytical work was done in the Water Laboratory of the Institute of Land Drainage and Improvement, at the Royal Institute of Technology, Stockholm, under the superision of Dr. Neeme Armolik. The tritium analyses were made by the International Meteorological Institute in Stockholm. Oxygen tests were made in the field by the Winkler method, as were some tests of pH and $\varkappa$.

The lake and catchment areas have been calculated from the map ("Björnöya", 1:25,000). In the great plain area the watersheds were sometimes rather hard to locate and incidental errors can be expected i areal statements.

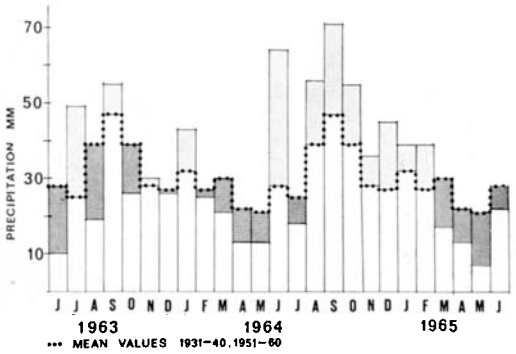

Fig. 2. Monthly mean precipitation values on Björnöya, June 1963–June 1965.

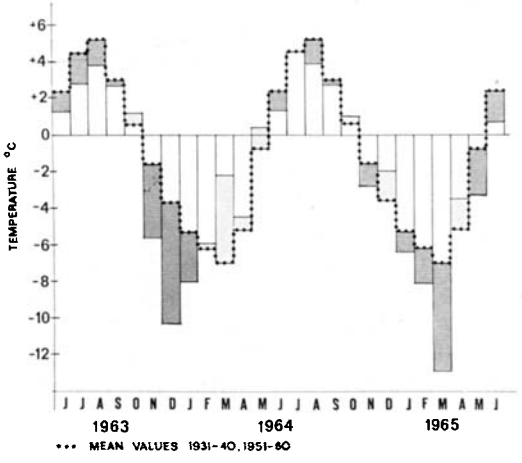

Fig. 3. Monthly temperature values on Björnöya, June 1963–June 1965.

Table 2. *Chemical composition of precipitation and snow samples from Björnöya*

		Altitude, m	$\varkappa \times 10^6$	Ph	Na^+, mg/l	K^+, mg/l	Ca^{++}, mg/l	Mg^{++}, mg/l	Cl^-, mg/l	SO_4^-, mg/l	Alkalinity, mekv/l	$Ca^{++}+Mg^{++}$, mekv/l	TU
By the sea	I	30	70	6.30	11.5	1.0	2.6	2.1	19.7	—	0.040	0.20	510
Meteorological station	II	15	22	6.80	1.5	0.4	4.8	0.4	2.1	—	0.132	0.20	360
Misery	III	250	24	6.36	3.3	0.8	1.8	0.4	5.4	0.8	0.046	0.08	544
Misery	IV	390	33	6.14	4.9	1.0	2.0	0.57	8.7	1.4	0.030	0.08	504
Misery	V	530	65	6.40	9.8	1.7	2.6	0.7	15.4	4.3	0.056	0.12	455

Analytical results

The analytical results, together with other appropriate data, are given in Tables 2 and 3. The sampling stations are indicated by symbols, which can be found on the map (Fig. 1).

A. Composition of precipitation

It was only possible to take one sample of precipitation, owing to the extremely dry and sunny weather during the expedition period on Björnöya. Snow samples were taken at 30,240, 390 and 530 m a.s.l. (see Table 2). The apparent increase in ion content in snow samples on Mount Misery was probably due to a very high deposition of snow in the form of rime at higher levels (Eriksson, 1952).

Owing to the relative smallness of the island, no variation in the atmospheric ion content, at varying distances from the sea, could be expected.

The precipitation samples are certainly few in number to permit extrapolation of the total ion content of the island's precipitation during a year. However, the maritime climate, together with the fact that the bulk of the total precipitation comes down as very fine drizzle and rime ensures a fair chance of the existing samples being representative of the total precipitation. No complications from turbulence caused by vegetation (Tamm, 1953) were possible, for natural reasons. Plotting the different ions in surface waters in relation to altitude also yields no significant result.

B. Composition of surface waters

As can be seen from Table 3, the results of the analysis vary from sample to sample. To make it easier to handle the material, the waters are classified into groups according to the geology of their drainage areas; the grouping is not dependent on the geographical location. The groups are given in Table 1 and the different geological areas are mapped (see Fig. 1).

The various groups are marked with their electrolytes from the rocks. These differences can be seen in Fig. 4, where the average ionic composition of the groups is shown.

If it is assumed that different ions are brought to the surface in the same ratio, then the differences in the ion contents of lake and river waters are due to weathering and mineral transformation in bedrock and loose deposits (Table 4). In this area one can premise that the predominant ion variation is due to climate, water and rock composition, since vegetation is rare.

It was decided that no attention should be paid to Lake Bugetjärn (lake no. 1, Table 3), as the content of electrolytes is extremely high, probably due to the fact that the catchment area is a resting-place for migratory birds (mainly different kinds of geese), thus causing eutrophication.

Chloride

The analyses were made by the mercuric-nitrate method.

The content of chloride in different rocks varies a good deal, depending on their mineral composition but is, as a rule, very small; for

Table 3. *Chemical composition of surface waters of Björnöya*

	Geological group	Lake area, km²	Catchment area, km²	Altitude, m	Catchment land area, km²	Catchment water area, km²	$\varkappa \times 10^6$	Ph	K^+, mg/l	Ca^{++}, mg/l	Mg^{++}, mg/l	Cl^-, mg/l	SO_4^-, mg/l	Alkalinity, mekv/l	$Ca^{++} + Mg^{++}$, mekv/l	Non carbonate hardness, mekv/l	TU	Na^+, mg/l
1	II	0.009	0.125	31.7	0.116	0.009	1216	6.90	9.0	15.3	2.1	382.0	—	0.500	3.08	2.58	—	199.0
2	II	0.059	0.313	28.0	0.254	0.059	178	6.74	1.6	6.0	2.9	46.1	8.4	0.316	0.68	0.36	—	32.0
3	II	0.096	1.750	20.4	1.454	0.296	223	6.78	1.9	5.5	3.2	64.6	10.7	0.272	0.76	0.49	—	39.0
4	I + II	—	0.313	12.0	0.264	0.049	163	6.86	1.6	4.2	2.4	46.1	8.2	0.172	0.50	0.33	—	27.5
5	I + II	0.048	0.313	14.0	0.264	0.049	198	6.80	1.4	3.4	2.4	70.3	9.6	0.092	0.50	0.41	—	35.5
6	I	0.004	0.126	12.0	0.122	0.004	236	6.10	2.3	5.3	3.2	71.6	8.6	0.080	0.62	0.54	—	39.0
7	I	0.005	0.063	12.0	0.058	0.005	229	5.60	1.9	3.0	3.2	72.0	10.1	0.012	0.46	0.45	—	43.5
8	I	0.049	0.625	17.8	0.514	0.111	219	6.58	1.7	4.2	2.5	49.6	—	0.116	0.64	0.52	—	35.0
9	II	0.044	0.688	25.4	0.613	0.075	190	6.60	1.9	6.0	2.0	49.7	—	0.132	0.52	0.39	—	30.5
10	I	0.029	0.378	31.9	0.299	0.079	151	5.24	1.9	9.3	2.1	45.2	—	0.000	0.32	0.32	—	26.5
11	II	0.646	6.188	32.3	5.073	1.115	256	6.24	2.7	3.2	2.4	60.6	10.0	0.096	0.50	0.40	509	35.5
12	II	0.134	1.689	19.3	1.324	0.365	214	6.96	1.6	7.2	2.7	59.2	10.6	0.316	0.74	0.42	—	32.5
13	II	0.073	2.313	24.9	1.884	0.429	236	6.92	1.7	6.5	3.6	67.6	11.8	0.285	0.80	0.52	—	38.5
14	I	0.021	0.938	28.5	0.873	0.065	132	5.56	1.2	2.2	0.9	41.4	5.2	0.000	0.32	0.32	—	25.5
15	I	0.038	0.250	33.4	0.191	0.059	111	6.16	1.2	2.4	0.8	32.1	4.1	0.024	0.26	0.24	—	20.5
16	I + II	1.040	8.375	31.6	5.804	2.571	129	6.86	1.0	4.6	1.6	32.8	6.2	0.204	0.48	0.28	—	20.0
17	II	—	3.687	29.0	3.331	0.356	143	6.60	1.2	5.0	2.2	36.6	5.3	0.136	0.44	0.30	—	22.5
18	I + II	0.975	8.188	29.6	6.088	2.100	121	6.54	1.0	3.2	1.0	33.1	7.1	0.065	0.34	0.28	—	20.0
19	I	0.422	1.875	32.7	1.328	0.547	147	6.40	1.2	3.4	2.2	41.5	7.2	0.112	0.44	0.33	—	28.0
20	II	0.020	0.063	31.6	0.043	0.020	145	6.94	1.2	3.6	2.2	40.6	8.0	0.140	0.48	0.34	807	26.5
21	II	0.327	1.312	40.2	0.966	0.346	111	6.16	1.2	2.4	1.6	31.6	6.7	0.040	0.34	0.30	—	21.0
22	I	—	3.313	44.0	2.619	0.694	99	5.46	0.8	2.8	1.6	27.4	6.2	0.006	0.26	0.25	—	15.5
23	I	0.494	3.313	45.8	2.619	0.694	94	5.72	1.2	2.2	0.7	27.6	4.8	0.000	0.24	0.24	—	16.0
24	I	0.183	2.250	26.2	1.848	0.402	106	5.56	1.2	2.0	1.3	29.1	6.2	0.000	0.28	0.28	—	22.5
25	I + II	—	14.687	20.0	13.856	0.831	140	6.34	1.0	6.4	1.8	35.3	10.6	0.060	0.40	0.34	—	24.0
26	I	0.085	2.062	33.0	1.927	0.135	178	5.98	1.9	3.0	3.0	50.8	9.8	0.024	0.48	0.24	539	30.5
27	I	0.106	0.500	79.7	0.394	0.106	139	5.70	1.4	2.6	2.3	40.8	8.2	0.020	0.36	0.16	514	23.5
28	I	0.091	0.313	58.0	0.222	0.091	130	5.06	1.4	2.0	2.1	35.8	7.9	0.000	0.34	0.34	—	21.5
29	I + II	0.348	4.688	32.8	4.146	0.542	152	6.64	1.2	3.6	2.6	44.1	8.4	0.092	0.48	0.39	—	26.0
30	I + II	—	4.688	32.0	4.146	0.542	153	6.44	1.2	4.4	2.0	42.0	6.7	0.076	0.44	0.36	—	23.0
31	I + II	0.931	5.875	30.9	4.800	1.075	196	6.66	1.4	5.2	2.8	53.7	—	0.152	0.60	0.45	—	30.5
32	I + II	—	5.875	29.0	4.800	1.075	185	6.80	1.6	7.4	2.1	48.5	6.2	0.704	0.66	—	—	27.0
33	II	—	4.250	20.0	3.500	0.750	187	7.54	1.2	12.1	2.7	41.2	7.1	0.608	0.94	0.33	—	24.0
34	I	0.068	0.688	92.8	0.620	0.068	93	5.26	0.8	2.2	2.1	26.9	3.8	0.000	0.26	0.26	470	17.5
35	I	0.046	1.000	20.1	0.810	0.190	57	4.90	0.6	1.0	1.1	16.2	2.2	0.000	0.12	0.12	—	11.5
36	I	0.071	2.813	19.4	2.667	0.146	81	5.76	1.0	1.4	0.8	22.8	3.6	0.008	0.20	0.19	—	17.0
37	I	0.244	5.563	102.1	5.319	0.244	110	6.50	1.2	1.8	1.5	28.0	5.4	0.028	0.32	0.29	—	16.3
38	I + II	0.046	1.000	145.8	0.941	0.059	196	7.30	1.4	12.1	2.0	45.1	8.2	0.512	0.92	0.41	602	25.5
39	I + II	0.014	0.716	92.6	0.689	0.027	156	6.60	1.0	6.2	2.5	40.0	6.5	0.208	0.54	0.33	—	23.0
40	I + II	0.042	0.313	103.9	0.271	0.042	202	6.08	1.6	3.6	2.5	60.2	9.4	0.040	0.50	0.46	—	36.0
41	III	—	7.250	9.0	6.520	0.730	187	7.40	1.2	15.0	3.0	30.9	9.1	0.844	1.22	0.38	—	18.7
42	III	0.716	6.534	20.8	5.705	0.829	163	7.40	1.2	15.0	2.7	33.1	9.8	0.608	0.98	0.37	—	19.4
43	III	0.012	0.063	130.1	0.051	0.012	232	7.84	1.4	23.8	2.2	39.2	—	1.312	1.54	0.23	—	27.5
44	III	—	19.000	22.0	18.600	0.400	221	7.26	1.6	16.1	3.8	46.0	9.4	0.744	1.26	0.52	—	29.5
45	III	0.021	0.313	52.1	0.292	0.021	183	7.00	1.6	6.7	3.8	43.5	12.2	0.408	0.76	0.35	—	26.0

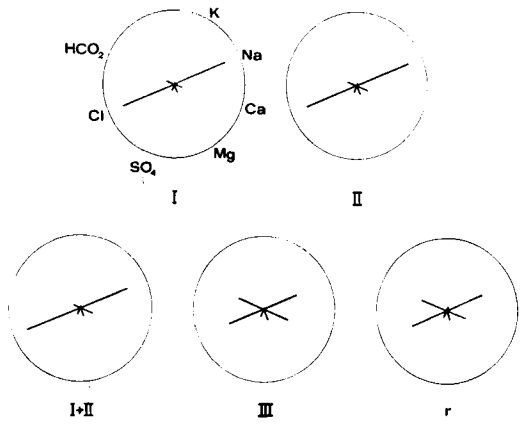

Fig. 4. Absolute concentrations (radius = 1 mval l^{-1}) of surface waters (I–III) and precipitation (*r*) of Björnöya.

sedimentary rocks, it is, on the average, 154 g ton^{-1} (Behne, 1953). Some sandstones have as small a chloride content as 20 g ton^{-1}.

That means that, as a rule, the chloride content originates from precipitation and the weathering release is almost negligible (Sverdrup, Johnson & Fleming, 1942).

In Fig. 5 the chloride content in mg l^{-1} – $\varkappa \cdot 10^6$ is plotted with regard to the classified groups. If the chemical analysis is handled statistically by regression analysis, a regression line equal to $y = kx + l$ is constructed. When the equation is linear to $y = kx$, i.e. when the ordinate in origo is equal to zero, it is unlikely that ion exchange occurs after the deposition of precipitations.

The waters from sandstone (I) and limestone (II) areas also give a good correlation with the line $y = kx$, which means that the sandstones and limestones are quite unaffected by the chloride content of the surface waters (Table 5).

Waters from areas in groups I and II, i.e. in which the water drains an area with confines between sandstones and limestones, are disturbed. The difference is not, however, statistically valid on the 5 % level, when compared with the waters from the sandstone area (I), and no consideration is given to it in the further treatment.

The chloride content of waters from the dolomite area (III) is more irregular, probably due to the more complicated composition and a higher chloride-content in the rocks.

Sodium

The ion content was established by flame photometry.

Sodium in mg l^{-1} is plotted against $\varkappa \cdot 10^6$ in Fig. 6. The deviation from $y = kx$ is rather small in waters of group I and I + II. Waters from limestone areas show greater weathering; when $\varkappa \cdot 10^6$ is zero, the sodium ion is equal to 6.79 mg. This difference is statistically valid on the 5 % level, compared with the waters of group I.

In conformity with chloride, waters from dolomites (III) give rise to still more complications.

If it is supposed that sodium and chloride are brought to the surface in the same ratio (Table 4), then it seems possible that the differences in the ion contents of lake waters are due to different weathering and mineral transformation in the heterogeneous bedrock. The analyses are, however, too few to yield any conclusions, owing to differences from the normal $y = kx$ for Na – $\varkappa \cdot 10^6$ if weathering or ion exchange is predominant.

Magnesium

The calcium and magnesium ion analyses were made by titration with EDTA.

The correlation coefficients when $\varkappa$ is calculated for magnesium indicate that magnesium is

Table 4. *The ratio of some elements to chloride in sea water and in different groups of surface waters (I–III) and precipitation (r) on Björnöya*

Ratio	I	II	I + II	III	*r*	Sea water
K/Cl	0.035	0.033	0.028	0.036	0.095	0.020
Ca/Cl	0.077	0.117	0.117	0.397	0.269	0.021
Mg/Cl	0.048	0.051	0.047	0.080	0.080	0.067
Na/Cl	0.622	0.607	0.577	0.628	0.604	0.566
SO_4/Cl	0.161	0.175	0.172	0.271	—	—

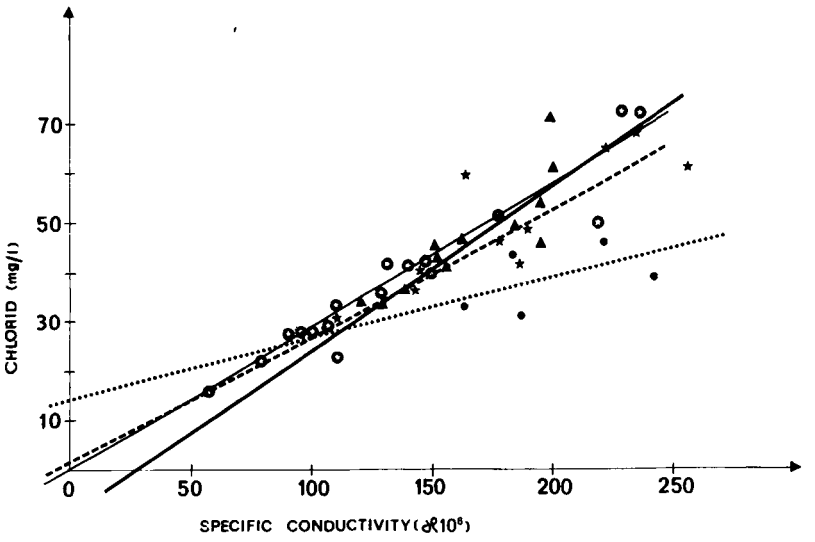

Fig. 5. Chlorid in relation to conductivity.

I: ○ ——, $y = 0.288x - 0.41$, $n = 17$, $r = 0.96$.
II: ★ – – –, $y = 0.256x + 1.66$, $n = 10$, $r = 0.93$.
I + II: ▲ ——, $y = 0.335x - 9.69$, $n = 12$, $r = 0.86$.
III: ● ...., $y = 0.121x + 14.65$, $n = 5$, $r = 0.53$.

rather easily weathered, especially in the dolomites (Rankama; Sahama). The ratio of magnesium to chloride (Table 4) also indicates this.

Calcium

The ratio of calcium to chloride indicates that the weathering plays an important part as regards the calcium content of the waters (Emanuelsson, 1955), especially in the dolomite area.

Potassium

The ratio of potassium to chloride (Table 4) indicates that the behaviour of potassium is fairly uniform in waters from different groups. The absorption of potassium should be rather small in inorganic materials; owing to the relative lack of clays etc., the existing thin layers are only active during periods of thaw. Some potassium must, of course, be utilized by algae and thus removed as organic compounds.

The relative high potassium content of the high-level precipitation sampled, relative the snow sample by the sea (no. 1, Table 1), verifies that a sample taken in direct connection with the high edge of the island is affected by sea sprout (Sugawara).

Tritium

TU-analyses have been made for only a few samples (TU = tritium unit equal to 10^{-18} T/H).

The total atmospheric TU content was inincreasing in the early sixties, with a marked peak in 1963, and then declined at all events up to 1965. An increase of the TU values with correspondence in lake percentage in drainage area is thus expected, as a bigger water volume must react sluggishly, owing to the lower turnover in water masses. A regression analysis, with x = TU and y = lake percentage, also gives the equation:

$$y = 0.0885\,X - 31.0; \quad r = 0.70.$$

Evaporation

A. Chemical calculations

By studying the deposition of precipitation, it has been found that there is an ion concentration in surface waters due to the evapotranspiration of moisture.

The hydrological equilibrium equation is usually written:

$$r = E + T + R \pm M,$$

where r = precipitation, E = evaporation, T =

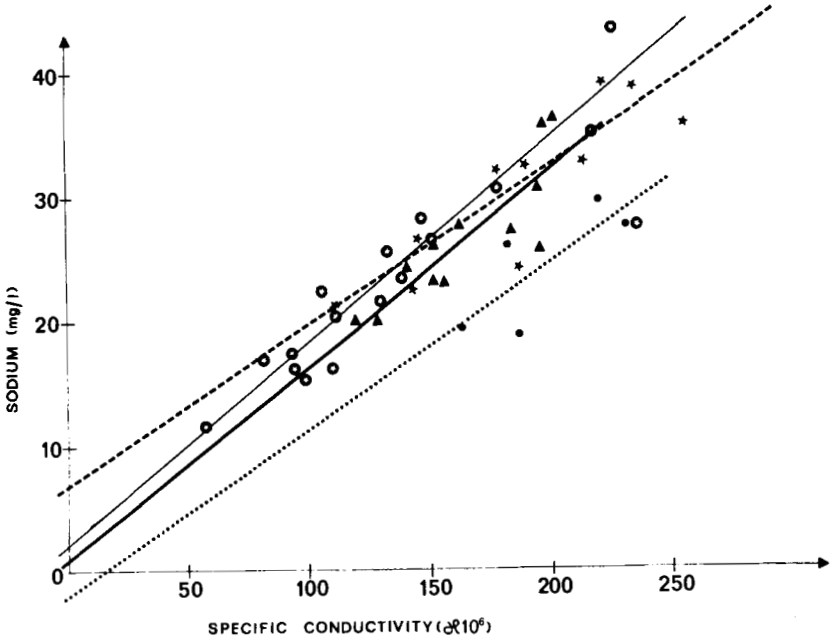

Fig. 6. Sodium in relation to conductivity.

I: ○ ——, $y = 0.164x + 1.86$, $n = 17$, $r = 0.97$.
II: ★ – – –, $y = 0.124x + 6.79$, $n = 10$, $r = 0.87$.
I + II: ▲ ——, $y = 0.156x + 0.55$, $n = 12$, $r = 0.85$.
III: ● . . . . , $y = 0.134x - 2.19$, $n = 15$, $r = 0.78$.

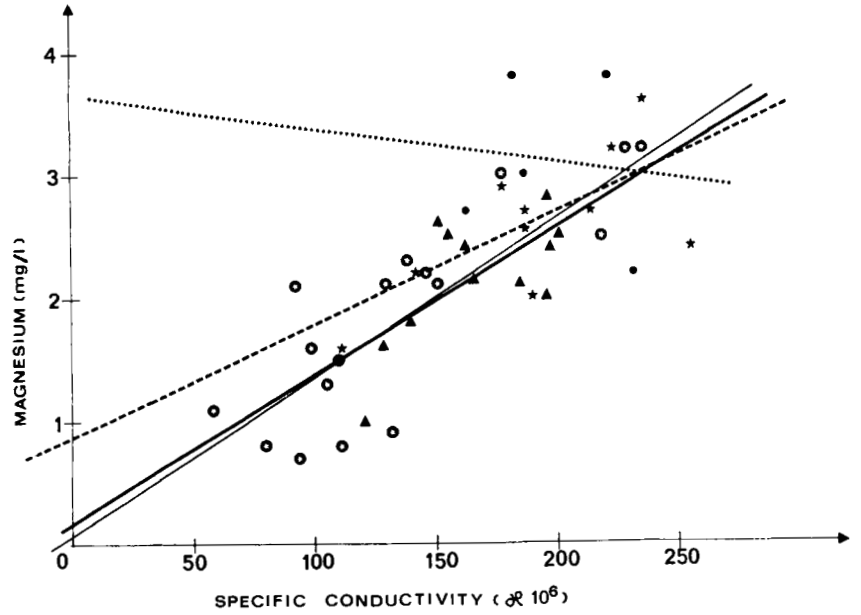

Fig. 7. Magnesium in relation to conductivity.

I: ○ ——, $y = 0.013x + 0.025$, $n = 17$, $r = 0.83$.
II: ★ – – –, $y = 0.009x + 0.882$, $n = 10$, $r = 0.68$.
I + II: ▲ ——, $y = 0.012x + 0.172$, $n = 12$, $r = 0.68$.
III: ● . . . . , $y = -0.003x + 3.700$, $n = 5$, $r = 0.12$.

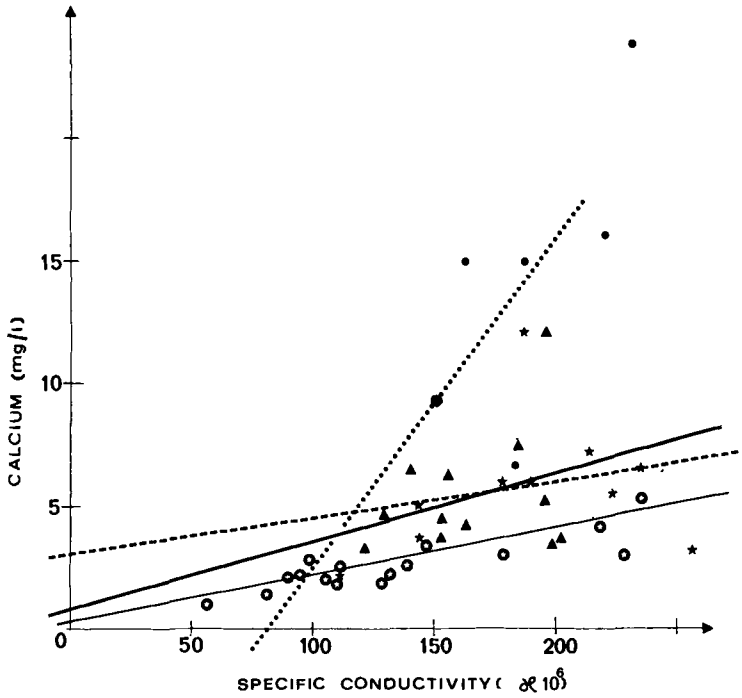

Fig. 8. Calcium in relation to conductivity.
I: ○ ——, $y = 0.019x + 0.42$, $n = 17$, $r = 0.52$.
II: ★ – – –, $y = 0.014x + 3.06$, $n = 10$, $r = 0.24$.
I+II: ▲ ——, $y = 0.027x + 0.93$, $n = 12$, $r = 0.30$.
III: ● ...., $y = 0.138x - 11.97$, $n = 5$, $r = 0.65$.

transpiration, R = run-off, and M = differences in magazine.

These items are then subdivided for different purposes, for example, E in evaporation from lakes, rivers and soil, R in surface and subsurface run-off, and so on.

Owing to the special conditions on Björnöya, the hydrological equation is simplified for certain items which are usually hard to deal with under temperate conditions.

As practically no vegetation exists, the transpiration factor did not apply.

The small differences in height on the flat lowland only produce weak potentials for moving ground water (Gustafsson, 1967). Thus the possibilities of ground water with a temperature surplus being forced into the ground and maintaining a thawed zone in the permafrost (Alter, 1950) is almost negligible, and the subsurface run-off in the lower parts of the island is probably very local.

In the steeper parts of the island, on the other hand, pressure potentials are available and create a subsurface run-off, nevertheless, the amount of water leaving the island in this manner must be negligible. This is also confirmed by the lack of fluvial ice. Ground-water out-flow was only observed once during our visit to Björnöya.

The hydrological equation could thus be written:

$$r = E + R \text{ (surface)},$$

if we calculate over a period of multiples of a year, when the snow magazine could be omitted.

As the samples were only taken during a limited period, the mean electrolyte content for the year may differ from the values analysed. (Boyd, 1959) has shown that the chemical composition of arctic-lake waters changes with increased ice cover, since ions will concentrate in the water. However, a period of thaw in April caused a run-off, and the consequent mixing of ion-poor melting water and the more

Table 5

	Evaporation rate, Ch, %	S.E.
Land area	71.30	1.14
Water area	78.18	6.17
Catchment area	73.7	—

Table 6

	Evaporation rate, Na, %	S.E.
Land area	73.55	1.62
Water area	67.82	8.84
Catchment area	73.7	—

highly concentrated, shallow, lake water seems to have created a water with a salinity close to that of the mean electrolyte content of the year. This is further confirmed by the ion contents of shallow and relatively deep lakes, which are quite similar and in which no systematic deviation can bi observed.

Thus, if no ion exchange appears after the precipitation reaches the ground, it should be possible to calculate the actual evaporation.

If the concentration of a specific ion in the precipitation is C_P and the concentration in the evaporated surface water is C_E, the evaporation expressed as a percentage E is

$$E = 100 - \frac{C_P}{C_E}. \qquad (1)$$

The chloride content of the water samples indicates that the influence of bedrock (possibly dolomites) is of negligible importance.

During winter the evaporation from snow and ice is constant for the whole area. In summertime the evaporation rates from the land surface and the water surface should be different on Björnöya, where there is a bare rock and soil surface; if this is the case, it seems possible to distinguish the evaporation from different areas.

$$a_1 \cdot x + b_1 \cdot y = (a_1 + b_1) z_1, \qquad (2)$$

where a_1 = land area, b_1 = water area, x = evaporation rate (land surface), y = evaporation rate (water surface), and z_1 = catchment area.

A statistical processing of equation (2), based on the calculated evaporation of chloride ions, according to equation (1), from 39 catchment areas (2–40, Table 2), is shown in Table 5.

To check if a correction coefficient for sandstone waters (I) is necessary, the calculated evaporation rate, based on chloride, is plotted against those based on sodium. An absolute agreement would give the regression equation $y = x$, i.e. $K = 1$ and the ordinate *in origo* is equal to zero. In Fig. 10 the evaporation rates for chloride are plotted against the evaporation rates for sodium (Group I, sandstone waters):

1. With uncorrected values,
2. With a correction coefficient of -1 mgl^{-1} (equal to half the value when $\varkappa \cdot 10^6$ is zero) (Fig. 6),
3. With a correction coefficient of -2 mgl^{-1}. An analysis of the equations indicates that there is a difference between the sodium and chloride ion concentrations in the sandstone area.

A similar analysis of evapotranspiration rates from "limestone waters" is more complex (cf. Fig. 6). A correction of -3.5 mg l^{-1} (equal to half the value when $\varkappa \cdot 10^6$ is zero) gives, after calculating the evapotranspiration, a plotting line with too small values in the expected evaporation rates based on sodium, compared with the corresponding figures based on chloride, when the waters have a higher ion concentration. A correction coefficient calculated on a hyperbolic correlation between hydrogen and sodium gives a better connection based on chloride in higher concentrations, but the sum total of this correlation is not so good.

The plotting of evapotranspiration based on uncorrected sodium values against values from chloride gives an even more unsatisfactory equation.

This review of the evaporation rates from chloride and sodium confirms that an apparent weathering and mineral transformation occurs both in the sandstone and in the limestone areas. The weaker limetones should also create better conditions for the formation (clayish soil and sediment) and thus yield better possibilities of chemical reactions. A calculation of the evaporation from land and water areas (eq. 2), based on sodium, is given in Table 6 .The total evaporation is of the same order of magnitude as that calculated from chloride; the differences in evaporation in water areas verify the complica-

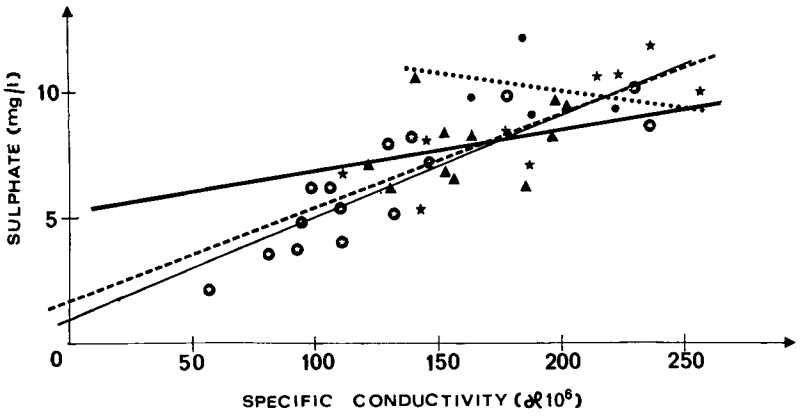

Fig. 9. Sulphate in relation to conductivity.

I: ○ ——, $y = 0.040x + 1.02$, $n = 15$, $r = 0.87$.
II: ★ – – –, $y = 0.037x + 1.72$, $n = 9$, $r = 0.83$.
I+II: ▲ ——, $y = 0.017x + 5.14$, $n = 11$, $r = 0.32$.
III: ● ...., $y = -0.015x + 12.85$, $n = 4$, $r = 0.25$.

tions in the sodium ion transformation in different rocks.

The rate of evaporation from the land area of the same size is related. When calculated from chloride and sodium, an evaporation rate of about 72.5 % is well within the standard errors.

The greater difference, both in the calculated evaporation rates and in the standard error from water areas, verifies the assumption that a higher ion-transformation capacity exists in lakes than in surface waters. The thawed clayish sediment zone on lake bottoms and percolating water through the thawed zones in summertime must produce an increase in the ion-transformation capacity.

Meteorological calculations

The evaporation formulas have been devised in the main along two lines, one based on differences in water pressure combined with turbulent transfer and the other based on energy-balance approaches, with several combinations between these two lines.

No radiation records are available from Björnöya, as the cloud and weather conditions are very unfavourable; calculations based on meteorological data seem more reliable (Albrecht, 1962).

Penman (1948) gives a formula

$$E_0 = 0.35\ (1 + 9.8 \times 10^{-3} u_2)\ (e_s - e_d), \qquad (3)$$

where E = evaporation rate from open water; u_2 = mean horizontal wind velocity in x direction at a height of 2 m in miles day^{-1}, and e_s and e_d = the saturation vapour pressures at the surface and the dewpoint. If the seasonal temperature of the shallow lakes is approximately that of the summer air-temperature cycle and a zero-temperature gradient exists, it is possible to calculate the saturation deficit from the meteorological data available, i.e. if it is possible to mix accurate temperature and wind observations with mean observations of relative humidity, and the formula applies to Björnöya conditions.

An evaporation estimate based on formula (3) gives 262 mm of water for the period 1 June 1963 to 31 May 1964 and 289 mm of water for the period 1 June 1964 to 31 May 1965 or, for the whole period, about 70 % of the recorded amount of precipitation.

Kuzmin (1957) gives a formula for evaporation from snow:

$$E_s = (0.18 + 0.098\ U_{10})\ (e_s - e_2), \qquad (4)$$

where E_s = evaporation rate in mm day^{-1}, U_{10} = average daily wind speed at a height of 10 m in msec^{-1}, e = saturated vapour pressure in mb 6 at snow-surface temperature and e_2 = vapour pressure in mb 6 of the air at a height of 2 m.

On the assumption that a layer of snow exists on Björnöya from November to April, a calcula-

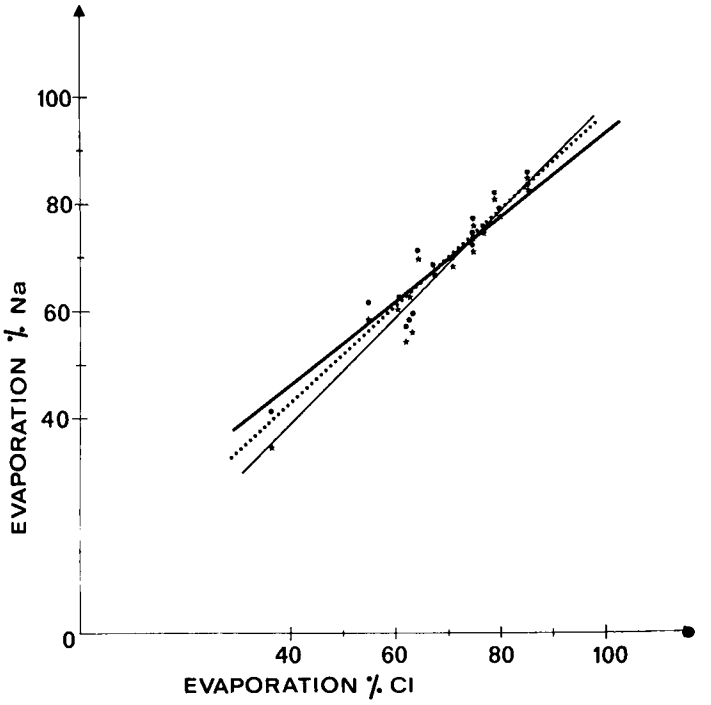
100
80
60
40
0
EVAPORATION % Na
40
60
80
100
EVAPORATION % Cl

Fig. 10

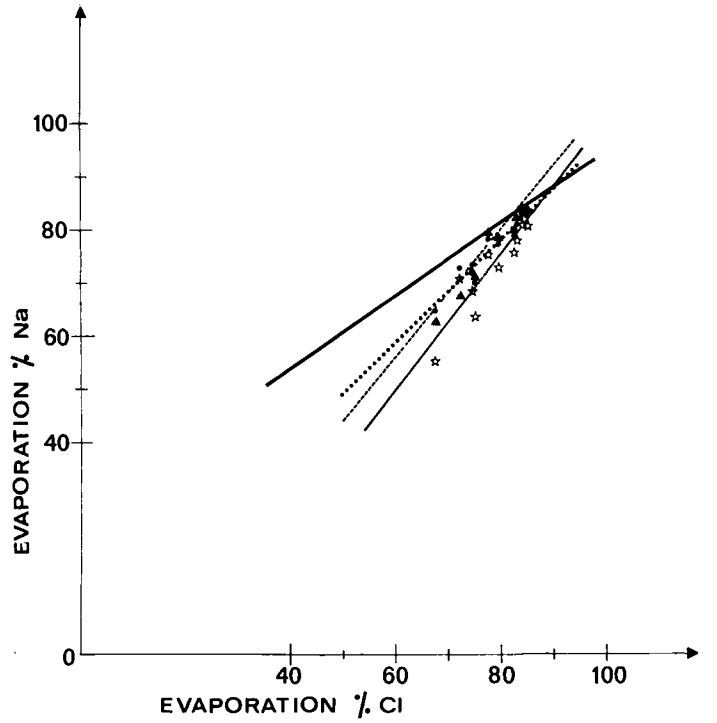
100
80
60
40
0
EVAPORATION % Na
40
60
80
100
EVAPORATION % Cl

Fig. 11

tion for evaporation from snow can be made with analogous reservations as before.

An evaporation estimate based on equations (3) and (4) gives 270 mm of water for the period 1 June 1963 to 31 May 1964 and 252 mm of water for the period 1 June 1964 to 31 May 1965 or, for the whole period, about 66 % of the recorded amount of precipitation.

Acknowledgements

This paper is based on fieldwork carried out under the auspices of the Department of Geography at Stockholm University. Most of the laboratory analyses of the water samples were made under the supervision of Dr. Neeme Armolik, who also made comments during the study of the chemical analyses. Special thanks are extended to Dr. Erik Eriksson for his invaluable advice and comments during all stages of the study. Without the assistance and co-operation of the abovementioned individuals, the preparation of this paper would not have been possible.

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Fig. 10. Evaporation sodium in relation to chlorid in waters group I.

Uncorrected: ——, $y = 0.811x + 14.8$, $n = 17$, $r = 0.96$.
Corr. -1 mg l^{-1}: ...., $y = 0.904x + 6.77$, $n = 17$, $r = 0.96$.
Corr. -2 mg l^{-1}: ——, $y = 0.999x - 1.38$, $n = 17$, $r = 0.96$.

Fig. 11. Evaporation sodium in relation to chlorid in waters group II.

Uncorrected: ——, $y = 0.658x + 28.22$, $n = 10$, $r = 0.85$.
Corr. -3.5 mg l^{-1}: ● ...., $y = 0.962x + 0.89$, $n = 10$, $r = 0.95$.
Corr. -7 mg l^{-1}: ★——, $y = 1.234x - 24.20$, $n = 10$, $r = 0.90$.
Corr. hyperbolic: ▲– – –, $y = 1.196x - 12.86$, $n = 10$, $r = 0.98$.

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ХИМИЧЕСКИЙ СОСТАВ ОСАДКОВ И ПОВЕРХНОСТНЫХ ВОД И ИХ СВЯЗЬ С ИСПАРЕНИЕМ НА ОСТРОВЕ БЬОРНЬОЯ, НОРВЕГИЯ

Пробы поверхностных вод и осадков были сделаня на о. Бьорньоя и проанализированы на различные компоненты. Содержание ионов в пробах связывается с различными скальными породами, найденными в этих местах. Была сделана попытка вычислить испарение, зная концентрации различных ионов. Степень испарения приблизительно оценена в 72 %, что соответствует метеорологическим оценкам.