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Kim Pilegaard

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Contents

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Biological monitoring of airborne deposition within and around the Ilimaussaq intrusion, Southwest Greenland

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The lichen *Cetraria nivalis* and the moss *Hylocomium splendens* were sampled within and around the alkaline Ilimaussaq intrusion in Southwest Greenland as monitors of the deposition of airborne metals and other elements. The intrusion is rich in U, Th, rare earth elements and heavy metals. The samples were analysed by instrumental neutron activation analysis (Na, K, Sc, Cr, Fe, Co, Zn, As, Se, Br, Rb, Sr, Ag, Sb, Cs, La, Ce, Nd, Sm, Eu, Yb, Tb, Lu, Hf, Ta, W, Au, Hg, Th and U) and by atomic absorption spectrophotometry (Cd and Pb).

Many elements characteristic of the rock-intrusion were found in significantly higher concentrations in plant samples from the intrusion than elsewhere. A factor analysis for *Cetraria* (including 28 elements determined in >70% of all samples) shows that 5 factors account for 79% of the total variation. The first factor (accounting for 52% of the total variation) included the elements characteristic of the intrusion (prominent members: Sc, Fe, Rb, Cs, La, Ce, Nd, Sm, Eu, Tb, Yb, Lu, Hf, Ta, Pb, and Th). For *Hylocomium* (26 elements) 4 factors account for 87% of the total variation. The first factor explained 49% of the total variance and included: Fe, Zn, Rb, Cd, Cs, La, Ce, Sm, Eu, Tb, Yb, Hf, Ta, Pb, and Th.

The source of elements found in the monitor organisms is the rocks of the intrusion, which weather into fine-grained particles subject to wind transport. Preoperational monitoring (*i.e.* monitoring before mining activities) is essential in areas where exposed mineralizations can act as natural sources of pollution.

Kim Pilegaard, Risø National Laboratory, P. O. Box 49, DK-4000 Roskilde, Denmark

Introduction

Background

The alkaline Ilimaussaq intrusion in Southwest Greenland is a unique geological structure in which a large number of chemical elements are enriched compared to average rock composition. The presence of high concentrations of uranium has led to plans of a uranium mine at Kvanefjeld in the northern part of the intrusion near the city of Narssaq.

The aim of the present study is twofold. Firstly to obtain a basic knowledge of the present amounts of aerially deposited elements in the terrestrial vegetation of the Narssaq area including the northern part of the intrusion, and secondly to investigate possible differences in element concentrations in the vegetation due to presence of rapidly weathering rocks in the intrusion.

The lichen *Cetraria nivalis* and the moss *Hylocomium splendens* were used as monitor organisms. Lichens and mosses have been extensively used as monitors of airborne metal pollution around various industrial sources. They accumulate elements by trapping small dust particles and by extracellular ion-exchange process (Richardson & Nieboer 1980). Due to the lack of a root system the uptake from the substrate is very small compared to the direct uptake from wet and dry deposition.

Most frequently monitoring has been carried out subsequent to initiation of industrial operations, whereas the reverse sequence is very uncommon. Preoperational monitoring is, however, very important in cases where a high »natural» level of pollution may exist. This is often the case in the mining industry, where exposed mineralizations can be sources of airborne pollution.

Uranium mine project

A project considering a uranium mine has been set up (Anonymous 1983) based on the relatively high concentrations (365 ppm U) and amounts (20,400 tonnes U) of uranium in the Kvanefjeld. The plan involves mining of

4.2 million tons of ore per year during 15 years. In connection with the project a pilot plant for the extraction of uranium was operated at the Risø National Laboratory. The ore used for extraction experiments was mined from June 1979 to August 1981.

The pre-feasibility study (Anonymous 1983) showed that there were technical and economic incentives to continue the development work, but still no decision to start production has been taken. A production in the mine can be initiated 9 years after the initiation of this development work. An environmental impact assessment of the mine has been given by Pilegaard (1983a and 1984).

The mining activity may impact the environment in several ways. In this context, the only item considered is airborne dispersal of elements to the terrestrial environment. Dust particles can be spread from activities in the mine itself, transportation, ore storage and waste dumps. Many of the elements enriched in the intrusion are potentially toxic in the terrestrial environment when consumed by *e.g.* sheep.

Site description

Topography

The Ilimaussaq intrusion is situated in Southwest Greenland near the city of Narssaq (Fig. 1). Kvanefjeld at 60°59'N, 46°00'W is a mountain in the northern part of the intrusion and reach 690 m a.s.l. The surrounding landscape is characterized by deep fiords (down to about 600 m depth) and high mountains (up to 1400 m a.s.l).

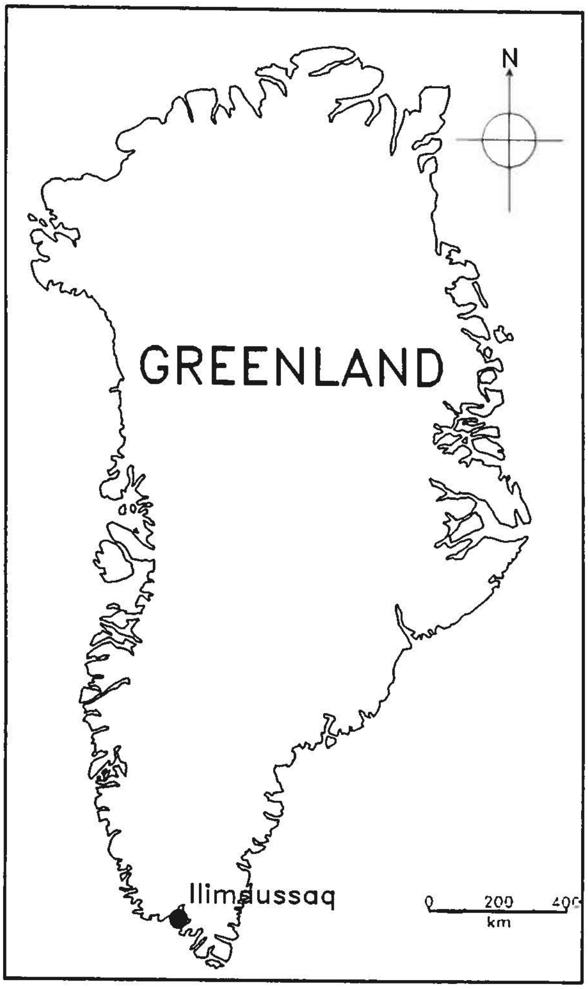

Fig. 1. Map of Greenland showing the location of the Ilimaussaq intrusion.

Geology and geochemistry

The geology of the Kvanefjeld area has been investigated during a century and an outline of the aspects related to uranium mining is given by Kalvig (1983). Only a short description will be given here.

Kvanefjeld is a part of the Ilimaussaq intrusion (Fig. 2). This consists of series of alkaline syenites and younger series of nepheline syenites. The latest derivatives (especially the naujaites and lujavrites) are strongly enriched in a number of elements such as Li, Be, F, P, S, Cl, Zn, Ga, Rb, Zr, Nb, Mo, Sn, Cs, rare earth elements, Ta, Tl, Pb, Th and U (Table 1).

The granites surrounding the intrusion are rather unaffected by weathering, whereas the syenites form mountains covered by loose debris of syenitic material with only scattered vegetation (Ussing 1912). The lujavrites weather into sand-sized end products and constitute a fairly stable geomorphological element compared to areas of naujaite, kakortokite and augitesyenite. The medium- to coarse-grained rocks show an extreme degree of disintegration of the surface to pebble-sized polymineralic grains. The bottom of the Narssaq valley is covered with superficial deposits of material eroded from the slopes mainly due to alluvial fan sedimentation (Emeleus & Upton 1976, Rose-Hansen *et al.* 1977).

The vegetation cover of the central area around Kvanefjeld is generally dense in the valley floor formed by alluvial and moraine deposits and very open and sparse on the Taseq slope which mainly consists of loose and eroded naujaite (Fig. 3).

Meteorology

The climate of the area is influenced by a major low-pressure system to the effect that north-easterly dry

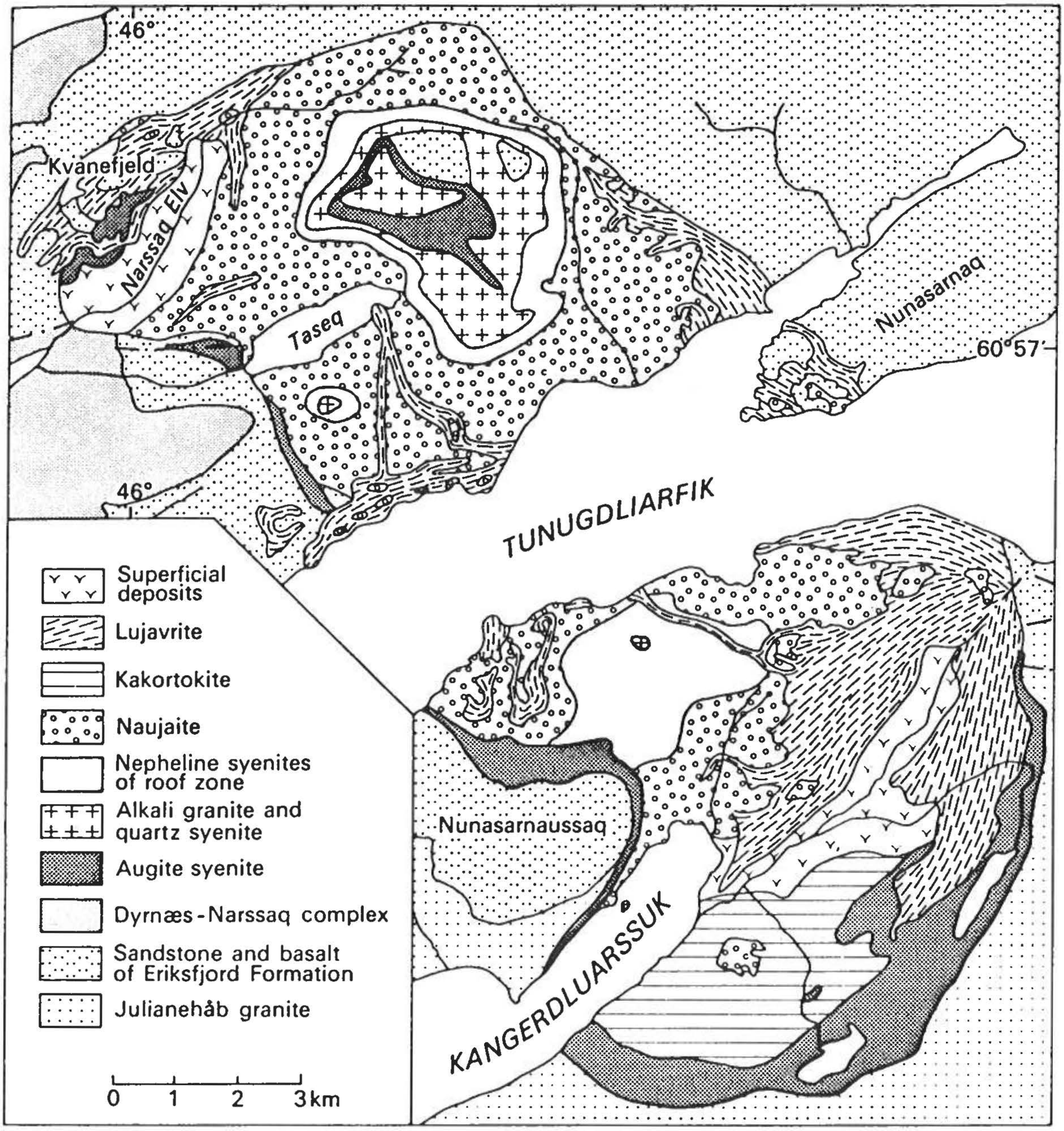

Fig. 2. Geological map of the Ilimaussaq intrusion (from Ferguson 1964).

winds from the icecap are predominant during winters while western and southwesterly humid winds from the sea predominates in the summer. The climate is arctic with a yearly mean temperature of +1°C, with December as the coldest month (−6°C) and July as the warmest (+7°C). Precipitation at sea level is approx. 890 mm/year.

Föhn winds are common in winter. The relative humidity of the föhn drops to 30–40% and the temperature rises 15–20°C within an hour and remains high for a day or two.

The meteorology of the Narssaq valley and the Kvanefjeld plateau was intensely studied during the period September 1979 to August 1983 as part of the Kvanefjeld Uranium Mine Pre-feasibility Study (Kristensen 1983). As expected, a marked difference in windspeed and direction was found between the valley and the plateau (Fig. 4).

Table 1. Average concentrations (ppm) of elements in the alkaline rocks of the Ilimaussaq massif and in main types of igneous rocks (after Gerasimovskii 1968).

Element	Ilimaussaq	Average rocks Acid	Basic	Ultrabasic
Li	310	40	15	0.5
Be	30	6.5	0.4	0.2
B	10	15	5	1
F	2,100	800	370	100
Na	86,000	27,700	19,400	5,700
Mg	2,200	5,600	45,000	15,900
Al	93,100	77,000	87,600	4,500
Si	236,400	23,000	240,000	190,000
P	214	700	1,400	170
S	910	400	300	100
Cl	8,800	240	50	50
K	33,500	33,400	8,300	300
Ca	7,780	15,800	67,200	7,000
Ti	2,070	2,300	9,000	300
V	(100)	40	200	40
Cr	(29)	25	200	2,000
Mn	1,900	500	2,000	1,500
Fe	70,300	27,000	85,600	96,500
Co	–	5	45	200
Ni	(41)	8	160	2,000
Cu	–	20	100	20
Zn	870	60	130	30
Ga	110	20	18	2
Br	–	1.7	3	0.5
Rb	590	200	45	2
Sr	(47)	300	440	10
REE	3,680	295	117	–
Zr	4,735	200	100	30
Nb	525	20	20	1
Mo	14	1	1.4	0.2
Sn	110	3	1.5	0.5
Cs	8.5	5	1	0.1
Ba	(100)	830	300	1
Hf	97	1	1	0.1
Ta	32	3.5	0.48	0.013
Tl	3.0	1.5	0.2	0.01
Pb	225	20	8	0.1
Th	38	18	3	0.005
U	62	3.5	0.5	0.003

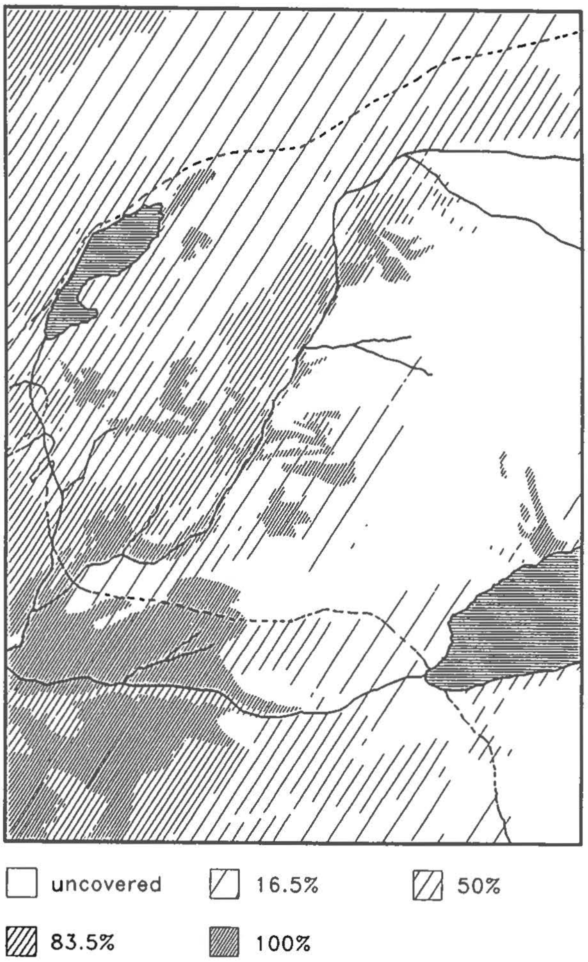

Fig. 3. Vegetation cover of the central Kvanefjeld area based on information given by Thorsteinsson (1980).

Materials and methods

Monitor organisms

Two species of cryptogams were chosen as monitor organisms: the lichen *Cetraria nivalis* (L.) Ach. and the moss *Hylocomium splendens* (Hedw.) B.S.G.

Cetraria nivalis has been used as a monitor organism of airborne elements in Greenland (Pilegaard 1983b and 1985) and in Canada (Puckett & Finegan 1980). *Hylocomium splendens* has been widely used as monitor organism of aerial heavy metal pollution in Scandinavia. A recent review is given by Gydesen *et al.* (1983).

Cetraria nivalis is an epigeic fructicose lichen that grows in loose tufts. The thallus is erect, sparingly branched, 2–6 cm high, straw yellow with a strong yellow or yellowish-brownish coloured band towards the base of the living part. There is almost always a thick mat of dead material below the living parts. At each site several (5–10) tufts were taken to form a composite sample. The material was, whenever possible, tufts growing on a mat of moss or at least on a mat of dead material of the lichen itself. This sampling procedure was followed in order to avoid contamination due to direct contact with the soil. In the laboratory the samples were carefully cleaned to remove all foreign material.

Hylocomium splendens is a large (5–10 cm) moss with stiff, bi- to tripinnate branches in often wide, green or brownish carpets on soils or rocks. The base of carpets consists of a layer of humus formed by dead moss segments, and contamination from the underlying soil or rock is thus eliminated. In the laboratory the samples were cleaned and only green living segments of the moss were analyzed.

Samples were dried for 3 days at 60°C.

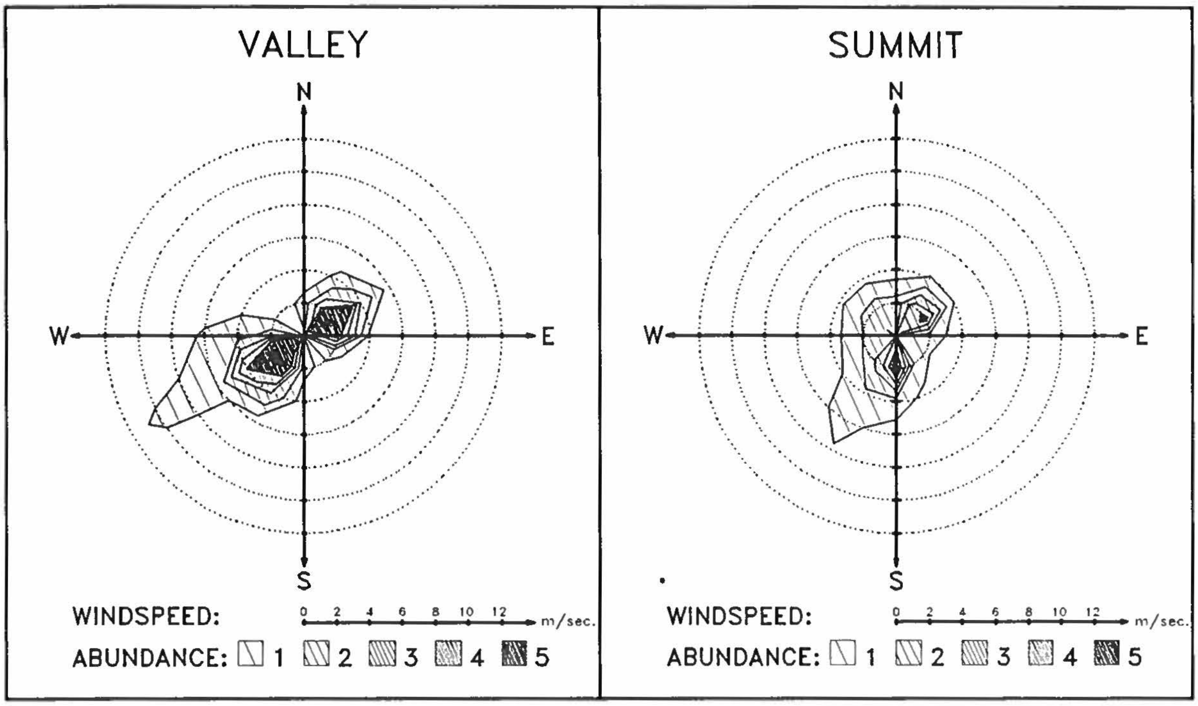

Fig. 4. Wind distribution at Narssaq valley and Kvanefjeld. The wind direction is rotated 180° compared to conventional wind roses in order to illustrate deposition pattern.

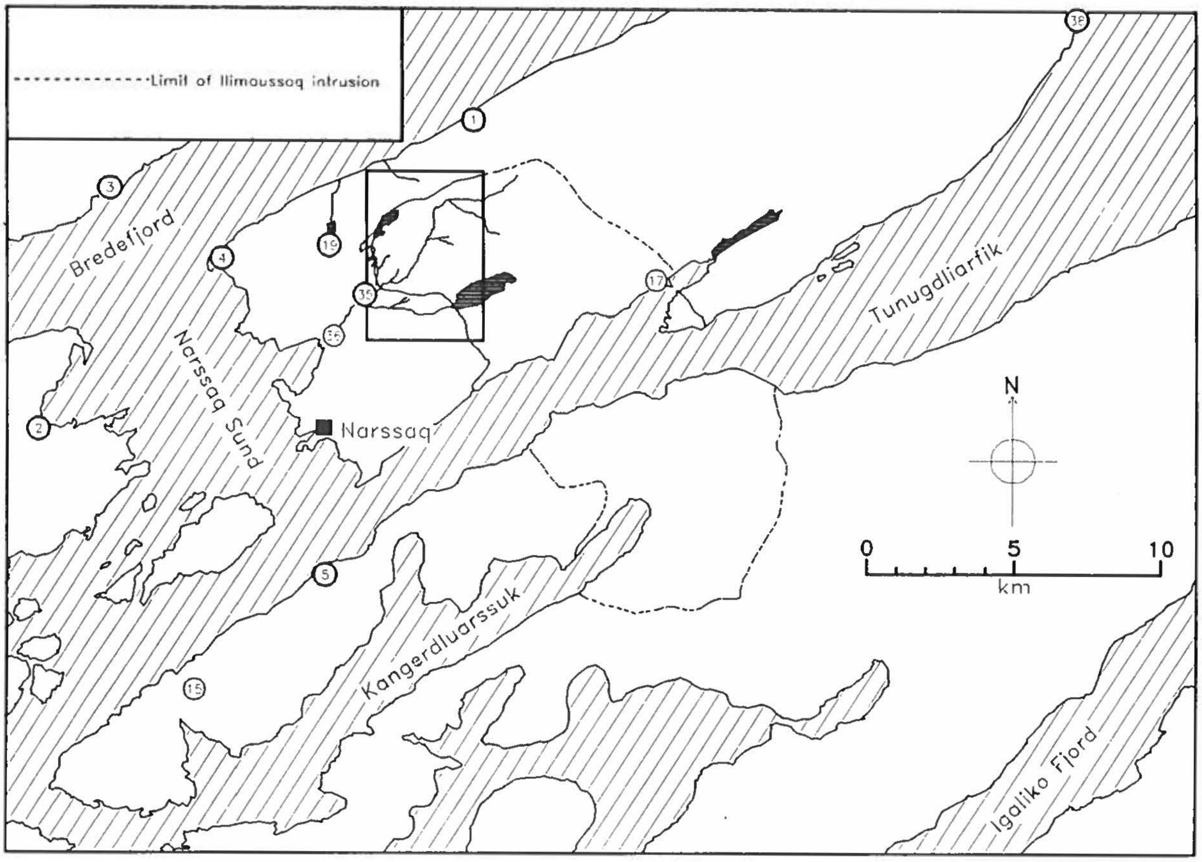

Fig. 5. Sampling sites for lichens and mosses. The outlined area is shown in Fig. 6.

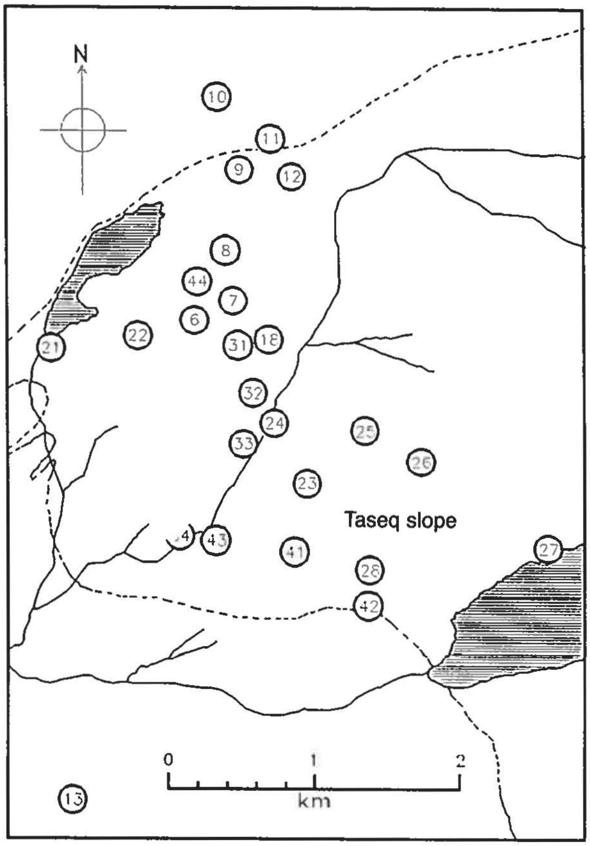

Fig. 6. Sampling sites for lichens and mosses in the central Kvanefjeld area.

Sampling sites

The lichens and mosses were sampled in late June 1979 (Figs 5 and 6). *Cetraria* was sampled at 36 sites (23 within the intrusion and 13 outside) and *Hylocomium* at 14 sites (6 within and 8 outside the intrusion). The distances between the sampling sites were shortest close to the entrance of the new mine at Kvanefjeld.

Samples of weathering products of the rocks were also made. Three samples of naujaite were taken at the Taseq slope (sampling sites Nos 41 to 43) and one sample of lujavrite at the Kvanefjeld plateau (sampling site No. 44). These samples were fractioned by sieving into the following size classes: <45μ, <71μ, <100μ, <250μ, <300μ. Each fraction was analysed separately.

Chemical analyses

Atomic absorption spectrophotometry

The elements Cd, Fe, Pb and Zn were analysed by atomic absorption spectrophotometry. One gram of dry material was digested to total dissolution in a mixture of 10 ml conc. HNO_3 (Merc, *pro analysi*) and 10 ml demineralized H_2O, evaporated to dryness, and the residue was dissolved in 25 ml lN HNO_3. The solutions were filtered and stored in polyethylene bottles in a refrigerator. The concentrations of the metals were determined with a Perkin-Elmer model 5000 spectrophotometer with graphite furnace HGA-76, D_2-arc background compensation, and automatic sampler AS-1. All analyses were duplicate. The analytical error of the determinations were 9–17% (Table 2).

Table 2. Analytical error (COV = coefficient of variation) of the determinations of metal concentrations in *Cetraria nivalis* and *Hylocomium splendens* calculated on the basis of duplicates.

Element	Species	N	COV*
Cd	Cetraria	34	11.1 %
	Hylocomium	20	15.1 %
Fe	Cetraria	36	16.5 %
	Hylocomium	20	11.9 %
Pb	Cetraria	35	14.5 %
	Hylocomium	20	11.2 %
Zn	Cetraria	36	15.8 %
	Hylocomium	20	8.7 %

*COV = 100 $\sqrt{(½N)\ \Sigma\ (\ln x_1-\ln x_2)^2}$, where N = number of sample sets.

Neutron activation analysis

The following elements were determined by instrumental neutron activation analysis (INAA): Na, K, Sc, Cr, Fe, Co, Zn, As, Se, Br, Rb, Sr, Ag, Sb, Cs, La, Ce, Nd, Sm, Eu, Yb, Lu, Hf, Ta, W, Au, Hg, Th and U.

Two hundred to four hundred mg of dried sample was placed in a small plastic vessel. The samples were irradiated in the 10 MW heavy-water moderated reactor DR3 at Risø National Laboratory. The irradiation times have been 1–12h, the decay times 3–7d and 25–30d with counting times of 1–4h. Two separate measurements were made in order to analyse as many elements as possible. The countings were made with a Ge(Li) detector. A detailed description of the applied INAA-method is given by Christensen & Damsgaard (1985).

Transformation of data

A logarithmic transformation of the data stabilizes the variance and gives a normal distribution as shown earlier (Pilegaard 1983b). The transformation $y = \ln x$ is used throughout the statistical calculations in this paper. Normal probability plots for selected elements in *Cetraria* and *Hylocomium* are shown in Figs 7 and 8. It is

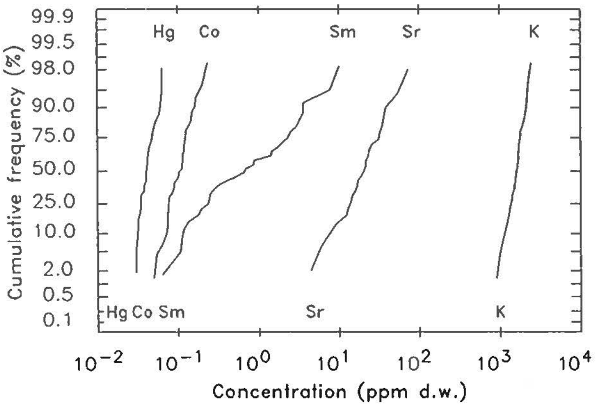

Fig. 7. Normal probability plot for selected elements in *Cetraria nivalis*.

seen that the transformation in general produces straight lines in the normal probability plots. Exceptions are elements (e.g. Au and Ce) with a few extremely high values (Appendices 3 and 4).

Geometric means ($\bar{x}_g$ = exp(mean of lnx) and geometric standard errors (s.e.$_g$ = exp (standard error of lnx) are given in the tables.

Factor analysis

The method of factor analysis has been applied in order to reduce the large amount of data variables. The factor analysis method applied in this study is described by Heidam (1981 and 1982). By means of a correlation matrix a large set of intercorrelated variables are reduced to a smaller set of uncorrelated variables, the factors. The variables are standardized to zero mean and unit variance. The factors can be interpreted as groups of elements with different origin, and the loading of each factor on each station (the factor score) can be calculated. The factor analysis relies on the existence of a correlation matrix of the variables. In case of missing values the program is able to generate new values by an iterative process using the factor scores. Only elements determined in more than 70% of the samples were included. The number of factors to be retained in the model is determined by the eigenvalues; *i.e.* factors that contribute a variance <1 are excluded from the model. After construction the principal factor model is rotated to fulfill the varimax criterion of either maximum or minimum loadings of the factors.

The applied program calculates factor loadings, communalities, absolute and relative factor variance contributions, standard deviations of factor loadings and factor scores. The factor loadings are simply the correlation coefficients between the original variables and the factors. The communality is the fraction of variance explained by the model.

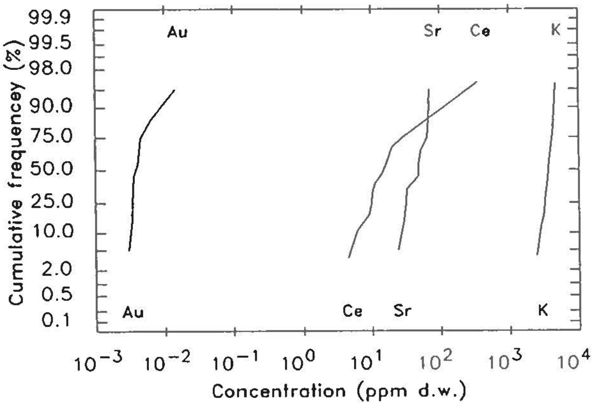

Fig. 8. Normal probability plot for selected elements in *Hylocomium splendens*.

Results

Element concentrations in weathering products

Lujavrite and naujaite are rich in rare earth elements with naujaite having the highest concentrations (Tables 3 and 4). Lujavrite shows the highest concentrations of U. Some elements are enriched in the smallest fractions, but the tendency is not clear.

Composite samples

To evaluate the sampling procedure of *Cetraria* 10 separate analyses were performed on material from one single tuft and compared with analyses of 10 separate tufts from one locality (Table 5). The coefficients of variation were found to be higher between the 10 separate tufts than within one single tuft. Therefore, the method of taking a composite sample of several tufts at each locality should be preferred to ensure that the results are representative of the locality.

Washing of samples

For the purpose of evaluating the amount of loosely attached particles to the surface of the plants, 4 samples of *Hylocomium*, covering a wide range of metal concentrations, were washed using the following procedure: 1g of dry moss was vigourously shaken with 100 ml demi-

Table 3. Element concentrations (ppm d.w.) in lujavrite in different size classes.

Element	<45μ	<71μ	<100μ	<250μ	<300μ	mena	s.e.
Na	35800	72100	71200	95000	79500	70720	9716
Sc	2.52	1.11	0.62	0.25	0.12	0.93	0.43
Cr	25.5	11.0	13.2	19.3	40.8	22.0	5.4
Fe	82600	17000	112000	97500	98200	102000	6100
Co	2.89	1.40	0.90	1.18		1.59	0.44
Cu	52	5	17	29	10	23	8
Zn	4140	2840	2690	2820	2260	2950	315
Rb	374	563	771	991	945	729	116
Ag	6.8	11.2				9.0	2.2
Sb	24	29	52	92	95	58	15
Cs	2.90	1.79	1.87	1.56	1.17	1.86	0.29
La	1420	815	870	1430	2290	1365	266
Ce	2210	1330	1510	2630	4020	2340	480
Sm	112	58	62	99	157	98	18
Eu	10.5	5.8	6.0	9.5	15.0	9.4	1.7
Tb	13.8	7.7	8.0	11.5	16.5	11.5	1.7
Yb	32.6	19.6	16.8	21.4	27.6	23.6	2.9
Lu	3.47	2.06	1.8	2.12	2.41	2.37	0.29
Hf	13.9	8.8	8.6	8.3	9.2	9.8	1.1
Ta	8.31	4.95	4.88	4.81	4.90	5.57	0.69
Pb	266	168	197	229	249	222	18
Th	237	127	132	233	371	220	45
U	376	284	293	449	777	436	90

neralized water for 30 min and dried and analysed as above. The concentrations of the washed samples were compared with those of the unwashed (Table 6). The differences between the two treatments were evaluated by means of paired t-tests. As seen from the table no significant differences were found.

Element concentrations

Analyses of the element concentrations in *Cetraria* and *Hylocomium* at each sampling site are given in Appendices 1–4. Tables 7 and 8 summarize these results in mean values and standard errors for the samples within

Table 4. Element concentrations (ppm d.w.) in naujaite in different size classes (means of 3 samples).

Element	<45μ	<71μ	<100μ	<250μ	<300μ	mean	s.e.
Na	25900	30400	31200	40900	50600	35800	4400
Sc	3.89	4.25	3.89	3.11	2.33	3.49	0.35
Cr	105	35	29	26	117	63	20
Fe	35700	40100	42500	53300	58200	45900	4200
Co	4.07	4.09	3.31	2.62	2.76	3.37	0.31
Cu	71	36	32	29	29	39	8
Zn	797	649	552	521	470	598	58
Se	4.3					4.3	
Br		10				10	
Rb	127	131	142	216	246	172	24
Sr	55					55	
Ag			31			31	
Sb	11.3	1.6	1.1	2.9	7.7	4.9	2.0
Cs	7.37	7.20	7.91	9.50	9.31	8.26	0.48
La	822	683	618	688	748	712	34
Ce	1370	1180	1170	1300	1260	1260	38
Sm	90	72	70	71	70	75	4
Eu	7.9	6.7	6.0	6.1	5.7	6.5	0.4
Tb	9.9	8.1	7.4	7.9	7.9	8.2	0.4
Yb	29.5	26.5	24.4	23.8	41.1	29.1	3.2
Lu	3.46	3.22	3.09	3.47	3.73	3.39	0.11
Hf	41.6	46.0	49.6	66.7	72.2	55.2	6.0
Ta	20.1	20.3	21.3	26.5	26.6	23.0	1.5
Pb	199	140	130	115	105	138	17
Th	147	122	113	143	180	141	12
U	143	151	140	156	197	157	10

Table 5. Comparison of variations in metal concentrations of *Cetraria nivalis* within a single tuft and within several tufts from the same locality.

Elements		1 tuft*	10 tufts**
Cd	$\bar{y}$***	-2.1491	-1.8851
	s_y^2	0.0202	0.0434
	COV_y****	14 %	21 %
Fe	$\bar{y}$	5.7707	4.9092
	s_y^2	0.0633	0.1644
	COV_y	25 %	41 %
Pb	$\bar{y}$	2.8789	1.9990
	s_y^2	0.0450	0.1297
	COV_y	21 %	36 %
Zn	$\bar{y}$	3.5725	3.3742
	s_y^2	0.0147	0.0376
	COV_y	12 %	19 %

* sampling site no. 18
** sampling site no. 36
*** $y = \ln x$
**** $COV_y = 100\ s_y$

and outside the intrusion. In addition the values for background areas of Greenland (54 samples) are given.

Significant differences in the concentration means of the three groups of *Cetraria* were found for the following elements: Sc, Cr, Fe, Co, Zn, Se, Rb, Ag, Cd, Cs, La, Ce, Nd, Sm, Eu, Tb, Yb, Lu, Hf, Ta, Au, Hg, Pb, and Th. With the exceptions of Sc, Cr, Fe, Co, As, Se, Ag, Au, Hg, the highest mean concentration was found in samples from the Illimaussaq intrusion.

Extremely high concentrations (10–20 times higher than background values) were found for rare earth elements (especially La and Ce), Th and U. The highest concentrations of these elements were found at stations 26, 27 and 42 (Appendix 1) on the Taseq slope.

Significant differences in the concentration means of the three groups of *Hylocomium* were found for the following elements: Zn, Se, Rb, Cd, Cs, La, Ce, Sm, Tb, Yb, Hf, Pb, and Th, with the only exception of Se, highest mean concentrations were found in samples from the Ilimaussaq intrusion.

As for *Cetraria* extremely high concentrations were found in *Hylocomium* of rare earth elements, Th and U on the Taseq slope at stations 23 and 24 (Appendix 3).

Results of factor analyses

Only elements determined in more than 70% of the samples were included in the factor analyses. The 28 elements fulfilling this criterion in *Cetraria* were: Na, K, Sc, Cr, Fe, Co, Zn, Se, Br, Rb, Sr, Cd, Sb, Cs, La, Ce, Nd, Sm, Eu, Tb, Yb, Lu, Hf, Ta, Au, Hg, Pb, and Th.

Table 6. Comparison of metal concentrations in washed (w) and unwashed (uw) samples of *Hylocomium splendens*.

Station	Cd		Fe		Pb		Zn	
	uw	w	uw	w	uw	w	uw	w
3	0.080	0.101	601	605	7.6	6.6	71	51
13	0.265	0.247	650	643	5.4	6.0	74	72
23	0.480	0.380	5300	3600	43	43	442	410
32	0.517	0.664	809	813	7.5	9.0	402	446
t	–0.379 n.s.		0.997 n.s.		–0.523 n.s.		0.905 n.s.	

Table 7. Comparison of means $\bar{x}_g$ of elements (ppm d.w.) in *Cetraria nivalis* sampled within (group 1) and outside (group 2) the Ilimaussaq intrusion and from background areas of Greenland (group 3). Significance of differences tested by one-way analysis of variance (***: $p<0.001$, **: $p<0.01$, *: <0.05, n.s.: non significant).

Element	Group	n	$\bar{x}_g$	$s.e._g$	x_{min}	x_{max}	Significance of difference between groups
Na	1	23	657	1.062	353	1000	
	2	13	546	1.058	358	743	
	3	54	578	1.068	171	1300	
	all	90	592	1.044	171	1300	n.s.
K	1	22	1626	1.046	1080	2420	
	2	13	1505	1.072	920	2200	
	3	54	1643	1.034	816	2400	
	all	89	1616	1.026	816	2420	n.s.

Element	Group	n	$\bar{x}_g$	s.e.$_g$	x_{min}	x_{max}	Significance of difference between groups
Sc	1	23	0.059	1.070	0.033	0.130	
	2	13	0.040	1.097	0.023	0.086	
	3	54	0.142	1.113	0.019	0.455	
	all	90	0.094	1.090	0.019	0.455	***
Cr	1	23	3.84	1.156	0.78	9.7	
	2	13	5.53	1.264	1.53	24.5	
	3	54	2.76	1.068	1.08	7.2	
	all	90	3.32	1.071	0.78	24.5	***
Fe	1	23	268	1.110	99	600	
	2	13	134	1.112	62	277	
	3	54	252	1.087	58	812	
	all	90	234	1.064	62	812	***
Co	1	23	0.107	1.069	0.050	0.237	
	2	13	0.098	1.117	0.054	0.206	
	3	54	0.281	1.097	0.059	1.270	
	all	90	0.188	1.083	0.050	1.270	***
Zn	1	23	31.9	1.104	15.3	96.5	
	2	13	15.7	1.068	11.1	25.5	
	3	54	14.4	1.057	5.1	37.0	
	all	90	17.8	1.058	5.1	96.5	***
As	1	9	0.142	1.170	0.083	0.310	
	2	11	0.113	1.096	0.047	0.145	
	3	33	0.178	1.113	0.034	0.560	
	all	53	0.156	1.081	0.034	0.560	n.s.
Se	1	22	0.16	1.124	0.062	0.54	
	2	13	0.19	1.163	0.088	0.53	
	3	33	0.45	1.073	0.076	0.87	
	all	68	0.27	1.087	0.076	0.87	***
Br	1	23	1.44	1.054	0.99	2.23	
	2	12	1.47	1.073	0.97	2.63	
	3	54	1.49	1.056	0.58	3.63	
	all	89	1.47	1.037	0.58	3.63	n.s.
Rb	1	21	6.1	1.132	2.3	18.5	
	2	12	2.6	1.173	1.2	8.2	
	3	34	3.1	1.131	0.6	13.2	
	all	67	4.1	1.092	0.6	18.5	***
Sr	1	15	24.3	1.155	9.1	72.3	
	2	10	13.4	1.228	4.4	30.9	
	3	34	24.2	1.141	5.5	89.5	
	all	59	21.9	1.099	4.4	89.5	n.s.
Ag	1	1	0.11		0.11	0.11	
	2	5	0.09	1.306	0.05	0.16	
	3	23	0.21	1.170	0.04	0.71	
	all	29	0.17	1.158	0.04	0.71	***
Cd	1	19	0.17	1.088	0.10	0.33	
	2	13	0.13	1.084	0.10	0.20	
	3	41	0.09	1.112	0.01	0.37	
	all	73	0.11	1.077	0.01	0.37	***
Sb	1	18	0.068	1.082	0.04	0.21	
	2	12	0.085	1.265	0.04	0.85	
	3	34	0.080	1.094	0.03	0.18	
	all	64	0.077	1.070	0.03	0.85	n.s.
Cs	1	23	0.304	1.223	0.081	3.480	
	2	13	0.046	1.126	0.023	0.091	
	3	34	0.063	1.165	0.009	0.270	
	all	70	0.099	1.149	0.009	3.480	***
La	1	23	15.10	1.257	1.36	98.1	
	2	13	1.22	1.204	0.43	5.1	
	3	54	1.21	1.123	0.22	9.9	
	all	90	2.31	1.161	0.22	98.1	***

Element	Group	n	$\bar{x}_g$	s.e._g	x_{min}	x_{max}	Significance of difference between groups
Ce	1	23	25.30	1.212	3.28	98.7	
	2	13	2.62	1.199	1.04	10.5	
	3	53	2.47	1.111	0.44	14.7	
	all	89	4.55	1.146	0.44	98.7	***
Nd	1	17	11.70	1.312	0.81	55.1	
	2	8	1.17	1.205	0.47	2.8	
	3	8	1.54	1.465	0.23	5.6	
	all	33	4.09	1.291	0.23	55.1	***
Sm	1	23	1.71	1.240	0.19	10.1	
	2	12	0.18	1.178	0.06	0.54	
	3	54	0.19	1.125	0.03	0.95	
	all	89	0.33	1.149	0.03	10.1	***
Eu	1	23	0.145	1.215	0.023	0.78	
	2	12	0.020	1.190	0.008	0.057	
	3	54	0.026	1.143	0.002	0.13	
	all	89	0.039	1.136	0.002	0.78	***
Tb	1	9	0.199	1.488	0.030	1.250	
	2	9	0.026	1.258	0.010	0.090	
	3	19	0.032	1.174	0.006	0.090	
	all	37	0.048	1.210	0.006	1.250	***
Yb	1	21	0.303	1.290	0.035	2.300	
	2	11	0.029	1.191	0.014	0.083	
	3	30	0.061	1.141	0.008	0.187	
	all	62	0.092	1.172	0.008	2.300	***
Lu	1	19	0.040	1.303	0.005	0.260	
	2	11	0.004	1.182	0.001	0.010	
	3	21	0.009	1.170	0.001	0.025	
	all	51	0.013	1.197	0.001	0.260	***
Hf	1	23	0.140	1.169	0.038	0.72	
	2	13	0.044	1.145	0.023	0.14	
	3	53	0.075	1.113	0.012	0.45	
	all	89	0.082	1.090	0.012	0.72	***
Ta	1	17	0.101	1.238	0.024	0.500	
	2	8	0.021	1.145	0.015	0.038	
	3	1	0.040		0.040	0.040	
	all	26	0.060	1.226	0.015	0.500	***
W	1	2	0.060	2.000	0.062	0.25	
	2						
	3						
	all	2	0.060	2.000	0.062	0.25	
Au	1	20	0.003	1.168	0.001	0.020	
	2	12	0.004	1.167	0.002	0.010	
	3	47	0.004	1.110	0.001	0.026	
	all	79	0.004	1.083	0.001	0.026	*
Hg	1	15	0.039	1.061	0.030	0.062	
	2	13	0.044	1.167	0.033	0.065	
	3	38	0.062	1.062	0.014	0.122	
	all	66	0.052	1.047	0.014	0.122	***
Pb	1	19	10.0	1.119	4.5	22.0	
	2	13	6.1	1.080	3.8	8.4	
	3	41	2.4	1.169	0.3	24.6	
	all	73	4.1	1.138	0.3	24.6	***
Th	1	23	0.860	1.207	0.131	7.50	
	2	12	0.077	1.174	0.033	0.23	
	3	54	0.120	1.137	0.023	0.72	
	all	89	0.190	1.144	0.023	7.50	***
U	1	1	1.320		1.320	1.32	
	2	2	0.085	2.432	0.035	0.21	
	3						
	all	3	0.21	2.852	0.035	1.32	

Table 8. Comparison of means ($\bar{x}_g$) of elements (ppm d.w.) in *Hylocomium splendens* sampled within (group 1) and outside (group 2) the Ilimaussaq intrusion and from background areas in Greenland (group 3). Significance of differences tested by one-way analysis of variance (***: $p < 0.001$, **: $p < 0.01$, *: $p < 0.05$, n.s.: non significant).

Element	Group	n	$\bar{x}_g$	s.e.$_g$	x_{min}	x_{max}	Significance of difference between groups
Na	1	6	1560	1.237	988	3890	
	2	8	1010	1.196	572	2520	
	3	20	1330	1.134	520	7390	
	all	34	1280	1.098	520	7390	n.s.
K	1	5	3870	1.052	3390	4430	
	2	8	3400	1.074	2460	4600	
	3	20	3690	1.053	2410	5190	
	all	33	3640	1.037	2410	5190	n.s.
Sc	1	6	0.42	1.262	0.26	1.16	
	2	8	0.30	1.195	0.16	0.77	
	3	20	0.60	1.240	0.14	3.51	
	all	34	0.48	1.157	0.14	3.51	n.s.
Cr	1	6	4.55	1.263	1.57	7.62	
	2	8	3.77	1.193	1.90	6.21	
	3	20	6.51	1.183	2.17	30.60	
	all	34	5.37	1.127	1.57	30.60	n.s.
Fe	1	6	2790	1.315	1450	8100	
	2	8	1450	1.186	745	3510	
	3	19	1710	1.221	462	8980	
	all	33	1790	1.144	462	8980	n.s.
Co	1	6	0.53	1.250	0.30	1.19	
	2	8	0.60	1.100	0.37	0.89	
	3	19	1.08	1.225	0.24	4.47	
	all	33	0.82	1.146	0.24	4.47	n.s.
Zn	1	6	202.0	1.194	102.0	301	
	2	8	47.2	1.223	19.2	103	
	3	20	22.2	1.072	13.1	44	
	all	34	39.1	1.171	13.1	301	***
As	1	3	0.48	2.105	0.17	2.03	
	2	3	0.18	1.095	0.15	0.20	
	3	2	0.42	1.059	0.39	0.44	
	all	8	0.32	1.351	0.15	2.03	n.s.
Se	1	5	0.30	1.583	0.133	1.00	
	2	5	0.21	1.508	0.086	0.67	
	3	12	0.67	1.120	0.370	1.15	
	all	22	0.43	1.196	0.086	1.15	*
Br	1	6	9.2	1.158	5.40	14.4	
	2	8	9.0	1.198	3.70	17.2	
	3	20	6.0	1.162	1.55	25.6	
	all	34	7.1	1.111	1.55	25.6	n.s.
Rb	1	6	29.8	1.160	16.4	45.6	
	2	7	8.8	1.095	7.2	14.0	
	3	14	9.6	1.095	4.8	17.3	
	all	27	12.1	1.119	4.8	45.6	***
Sr	1	3	45.6	1.232	31.1	63.8	
	2	7	42.6	1.172	23.8	69.9	
	3	8	22.9	1.245	11.5	56.6	
	all	18	32.7	1.148	11.5	69.9	n.s.
Ag	1	2	0.47	3.152	0.15	1.47	
	2						
	3	3	0.90	1.122	0.75	1.11	
	all	5	0.69	1.494	0.15	1.47	n.s.
Cd	1	6	0.31	1.219	0.16	0.52	
	2	7	0.15	1.248	0.08	0.36	
	3	20	0.13	1.133	0.07	0.55	
	all	33	0.16	1.155	0.07	0.55	*

Element	Group	n	$\bar{x}_g$	s.e.$_g$	x_{min}	x_{max}	Significance of difference between groups
Sb	1	4	0.142	1.126	0.110	0.190	
	2	5	0.102	1.061	0.082	0.115	
	3	4	0.125	1.183	0.078	0.172	
	all	13	0.121	1.076	0.078	0.190	n.s.
Cs	1	6	0.436	1.472	0.135	1.88	
	2	8	0.147	1.242	0.072	0.52	
	3	13	0.103	1.262	0.036	0.61	
	all	27	0.157	1.204	0.036	1.88	**
La	1	6	16.9	1.404	4.50	50.0	
	2	8	5.2	1.291	1.86	22.8	
	3	20	3.5	1.310	0.79	24.1	
	all	34	5.0	1.225	0.79	50.0	*
Ce	1	6	45.8	1.694	9.20	353.0	
	2	8	10.1	1.181	4.40	17.4	
	3	20	6.9	1.280	1.75	48.0	
	all	34	10.6	1.234	1.75	353.0	**
Nd	1	6	15.7	1.762	2.9	152.0	
	2	3	5.4	1.648	3.0	14.7	
	3	3	10.5	1.452	5.2	18.2	
	all	12	10.9	1.388	2.9	152.0	n.s.
Sm	1	6	1.61	1.296	0.63	3.38	
	2	8	0.70	1.251	0.28	2.48	
	3	20	0.43	1.283	0.11	3.29	
	all	14	0.61	1.198	0.11	3.38	*
Eu	1	6	0.226	1.592	0.073	1.55	
	2	8	0.089	1.222	0.039	0.22	
	3	19	0.084	1.248	0.024	0.33	
	all	33	0.102	1.184	0.024	1.55	n.s.
Tb	1	6	0.259	1.706	0.061	2.21	
	2	7	0.059	1.286	0.025	0.20	
	3	7	0.122	1.328	0.038	0.30	
	all	20	0.119	1.269	0.025	2.20	*
Yb	1	6	0.598	1.701	0.151	4.21	
	2	8	0.176	1.169	0.093	0.35	
	3	8	0.241	1.247	0.084	0.56	
	all	22	0.275	1.217	0.084	4.21	*
Lu	1	6	0.087	1.484	0.028	0.305	
	2	3	0.031	1.222	0.024	0.046	
	3	1	0.052	1.000	0.052	0.052	
	all	10	0.060	1.323	0.024	0.305	n.s.
Hf	1	6	1.35	1.494	0.550	6.34	
	2	8	0.56	1.207	0.230	1.20	
	3	20	0.37	1.242	0.082	2.44	
	all	34	0.51	1.186	0.082	6.36	*
Ta	1	6	0.51	1.548	0.165	2.880	
	2	8	0.16	1.231	0.048	0.340	
	3	1	0.15	1.000	0.151	0.151	
	all	15	0.25	1.286	0.048	2.880	n.s.
Au	1	5	0.004	1.057	0.003	0.004	
	2	5	0.005	1.338	0.003	0.014	
	3	7	0.007	1.364	0.002	0.032	
	all	17	0.005	1.175	0.002	0.032	n.s.
Hg	1	5	0.093	1.130	0.071	0.138	
	2	5	0.088	1.117	0.073	0.134	
	3	13	0.102	1.102	0.060	0.178	
	all	23	0.097	1.066	0.060	0.178	n.s.
Pb	1	6	14.5	1.295	7.5	43.0	
	2	8	6.8	1.106	4.3	9.9	
	3	20	4.1	1.152	1.7	13.0	
	all	34	5.8	1.134	1.7	43.0	***

Element	Group	n	$\bar{x}_g$	s.e.$_g$	x_{min}	x_{max}	Significance of difference between groups
Th	1	6	3.50	1.667	0.490	16.40	
	2	8	0.56	1.252	0.250	1.24	
	3	20	0.35	1.287	0.075	1.86	
	all	34	0.58	1.258	0.075	16.40	***
U	1	2	3.90	1.992	1.950	7.77	
	2						
	3						
	all						

Twenty-four elements fulfilled the criterion in *Hylocomium:* Na, K, Sc, Cr, Fe, Zn, Se, Br, Rb, Sr, Cd, Cs, La, Ce, Sm, Eu, Tb, Yb, Hf, Ta, Au, Hg, Pb and Th.

Correlation matrices of the logarithmic transformed concentrations of *Cetraria* and *Hylocomium* were calculated. The matrices were diagonalized and analyses of eigenvalues for significance performed by means of a test statistic which measures individual eigenvalues in terms of the residual variance. The first 10 eigenvalues for *Cetraria* and *Hylocomium* show that the number of factors to be retained is 5 for *Cetraria* and 4 for *Hylocomium* (Fig. 9).

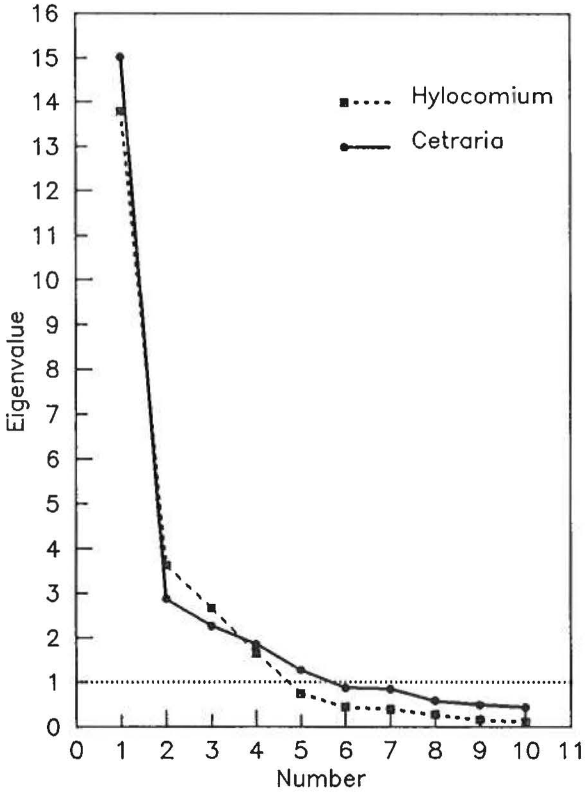

Fig. 9. The first 10 eigenvalues for the correlation matrices of *Cetraria nivalis* and *Hylocomium splendens*.

The rotated 5-factor solution for *Cetraria* is given in table 9. Factor loadings less than three standard deviations have been deleted for the sake of clearness. The 5-factor solution explained 79% of the total variation. The first factor included elements characteristic of the intrusion and accounted for 52% of the total variation. Prominent members (loadings > 0.7) of this factor were: Sc, Fe, Rb, Cs, La, Ce, Nd, Sm, Eu, Tb, Yb, Lu, Hf, Ta, Pb and Th.

Factor 2 (accounting for 5.6%) had Co as a prominent member.
Factor 3 (accounting for 7.5%) had Sr and –Sb as prominent members.
Factor 4 (accounting for 7.2%) had K as a prominent member.
Factor 5 (accounting for 7.6%) had Au and Hg as prominent members.

The rotated 4-factor solution for *Hylocomium* explained 87% of the total variation (Table 10). The first factor explained 49% and included the prominent members: Fe, Zn, Rb, Cd, Cs, La, Ce, Sm, Eu, Tb, Yb, Hf, Ta, Pb and Th.

Factor 2 (accounting for 13.5%) had Se and –Sr as prominent members.
Factor 3 (accounting for 10.8%) had K and –Br as prominent members.
Factor 4 (accounting for 10.7%) had Au as a prominent member.

When comparing Tables 9 and 10 it can be seen that there is a very good agreement in factor 1 of the two species. Considering the prominent members of the factors, it can be seen that both species has a factor including K (factor 4 in *Cetraria* and factor 3 in *Hylocomium).* Also the factor dominated by Au can be found in both species. Furthermore there is some agreement between factor 3 in *Cetraria* and factor 2 in *Hylocomium.* Thus the two species generally reveal the same uncorrelated groups of strongly intercorrelated elements.

Table 9. Varimax rotation of 5-factor solution for *Cetraria nivalis*. The table includes communalities, factor loadings, standard deviations (S.d.) of factor loadings and variance contributions (absolute and relative).

				Factors			
	Communality	1	2	3	4	5	S.d.
Na	0.5069	0.586					0.126
Sc	0.7789	0.708	0.488				0.084
Fe	0.8886	0.835	0.332	−0.238			0.060
Rb	0.8534	0.701	−0.220		0.539		0.069
Cd	0.6075	0.571		0.349		0.383	0.113
Cs	0.8222	0.815			0.374		0.076
La	0.9762	0.966		0.184			0.028
Ce	0.9751	0.968		0.165	0.101		0.028
Nd	0.9857	0.976		0.157	0.066		0.022
Sm	0.9918	0.977		0.159	0.066	−0.076	0.016
Eu	0.9702	0.970		0.147			0.031
Tb	0.8999	0.922					0.057
Yb	0.9727	0.947		0.192	0.182		0.030
Lu	0.9777	0.945		0.194	0.196		0.027
Hf	0.8789	0.924					0.063
Ta	0.9587	0.972					0.037
Pb	0.6968	0.821					0.099
Th	0.9077	0.890			0.315		0.055
K	0.8140				0.889		0.077
Zn	0.7736	0.594			0.642		0.085
Cr	0.5271		0.572			−0.415	0.124
Co	0.6856		0.760				0.101
Se	0.5217					0.633	0.124
Au	0.5752					0.721	0.117
Hg	0.7192					0.749	0.095
Br	0.4565			−0.593			0.132
Sr	0.9116	0.566		0.703		0.288	0.053
Sb	0.6011			−0.748			0.113
28	22.2343	14.455	1.555	2.089	2.011	2.123	Variances
100	79.41	51.6	5.6	7.5	7.2	7.6	Percentages

The factor scores of factor 1 (containing the elements characteristic of the intrusion) are shown for *Cetraria* and *Hylocomium* (Figs 10 to 13). The highest factor scores for both species are found within the limits of the Ilimaussaq intrusion especially on the Taseq slope and the Kvanefjeld plateau. The lowest values are found furthest away from the intrusion.

Discussion

Distribution of element concentrations

From the results of the analyses of element concentrations of *Cetraria* and *Hylocomium* it can clearly be seen (Tables 7 and 8) that some elements are highly enriched in samples from the Ilimaussaq intrusion. The most enriched elements are Fe, Rb, Cs, the rare earth elements, Hf, Ta, Pb and Th. These elements are clearly enriched also in rocks of the intrusion (Table 1). Therefore the rocks are supposed to be the source of the elements. Metals must have entered the plants as aerially deposited dust or as dissolved matter in the precipitation, because the lichens and mosses used in the investigation are unable to take up elements from their substrate.

Man-made dust producing activities in the years before the sampling (*i.e.* within the life-time of the monitor organisms: 5-15 years) are restricted to the construction of a road from the valley to the new gallery (autumn 1978 and spring 1979) and the excavation of the gallery, which was commenced less than a month before the sampling time. If human activities were the main sources of the elevated element concentrations of the monitor organisms within the intrusion, a gradient of concentrations rising towards the new road and the entrance to the gallery should be expected. Examination of the data shows, however, no clear trends, but high concentrations were prevalent throughout the area of the intrusion.

The highest concentrations were generally found at

Table 10. Varimax rotation of 4-factor solution for *Hylocomium splendens*. The table includes communalities, factor loadings, standard deviations (S.d.) and absolute and relative variance contributions.

				Factors		
	Communality	1	2	3	4	S.d.
Na	0.9552	0.731	–0.399	0.207	–0.468	0.067
Sc	0.9153	0.690	–0.416		–0.487	0.092
Fe	0.9788	0.869	–0.292	0.144	–0.343	0.046
Zn	0.8772	0.823		0.356		0.111
Rb	0.8896	0.916				0.105
Cd	0.6605	0.748				0.184
Cs	0.8825	0.867		–0.351		0.108
La	0.8884	0.853			0.335	0.106
Ce	0.9937	0.970	–0.133	–0.159	–0.100	0.025
Sm	0.9020	0.852			0.325	0.099
Eu	0.9781	0.907	–0.297	–0.248		0.047
Tb	0.9922	0.954	–0.161	–0.236		0.028
Yb	0.9365	0.936				0.080
Hf	0.9635	0.878	–0.312		–0.305	0.060
Ta	0.9415	0.919	–0.216		–0.222	0.076
Pb	0.8018	0.840				0.141
Th	0.7975	0.880				0.142
K	0.9373			0.947		0.079
Br	0.5813			–0.715		0.205
Hg	0.9136		0.463	0.596	0.586	0.093
Cr	0.7929	0.434	–0.713			0.144
Se	0.8973		0.915			0.101
Sr	0.9335		–0.898	–0.308		0.082
Au	0.9692				0.982	0.055
28	21.3793	12.990	3.245	2.584	2.561	Variances
100	89.08	54.1	13.5	10.8	10.7	Percentages

the SE slope of the Kvanefjeld, the Taseq slope and at station no. 17 (Appendices 1 and 3). These localities are characterized by lujavrite (SE slope of the Kvanefjeld and station no. 17) and naujaite (Taseq slope). These rocks have much higher concentrations of the above listed enriched elements than average acid or basic rocks (Tables 1, 2, and 3). The most probable explanation for the elevated concentrations within the intrusion is therefore dust-formation due to weathering of the intrusive rocks. As mentioned above, the rocks of the intrusion are highly weathering in contrast to the rocks in the surroundings, especially the granites.

Fe is frequently used as an indicator of windblown dust of crustal origin in analyses of elements in atmospheric particulates (Puckett & Finegan 1980). Fe is only slightly enriched in the intrusive rocks. Basic rocks, which surround the intrusion to the north and east, have higher concentrations of Fe than the intrusive rocks as an average. The elevated concentrations of Fe in the monitor organisms might thus exclusively be ascribed to the high rate of weathering. The higher concentrations of the other elements are a combination of high concentrations in the rocks and the high rate of weathering.

The weathering products can be transported with water and wind. Thus the delta of the Narssaq river contains material from the intrusion. The sample of *Cetraria* from the delta (station no. 36) showed concentrations of the elements characteristic of the intrusion well above the means of the concentrations in samples outside the intrusion (Appendices 1 and 2 and Table 7). The transport of particles with the wind seems, however, to be very limited since only a few of the stations close to the intrusion show high values (*e.g.* stations nos 10 and 11) (Appendix 2).

Djamgouz & Ghonein (1974) have determined the pick-up air velocities (*i.e.* the air speed required to lift and carry particles) for various types of coarse dusts (granite, silica, coal). They found the pick-up velocities for granite for the following size classes: 10–35μ : 4 m/s, 35–75μ : 6 m/s and 75–105μ : 7 m/s. If the dusts are wet, the air speed required is increased by 1 m/s. Wind speeds above 4 m/s are frequent both in the valley and on the plateau (Fig. 4), but since elevated concentrations are almost exclusively confined to the area within the intrusion, it might be implied that only a small fraction of the particles formed by weathering is within the size range which is likely to be transported by wind over great distances.

Observations in the field have shown that small particles are absent from the uppermost layers of the unvegetated erosion slopes. Probably the wind carries the particles away; thus the source strength is determined

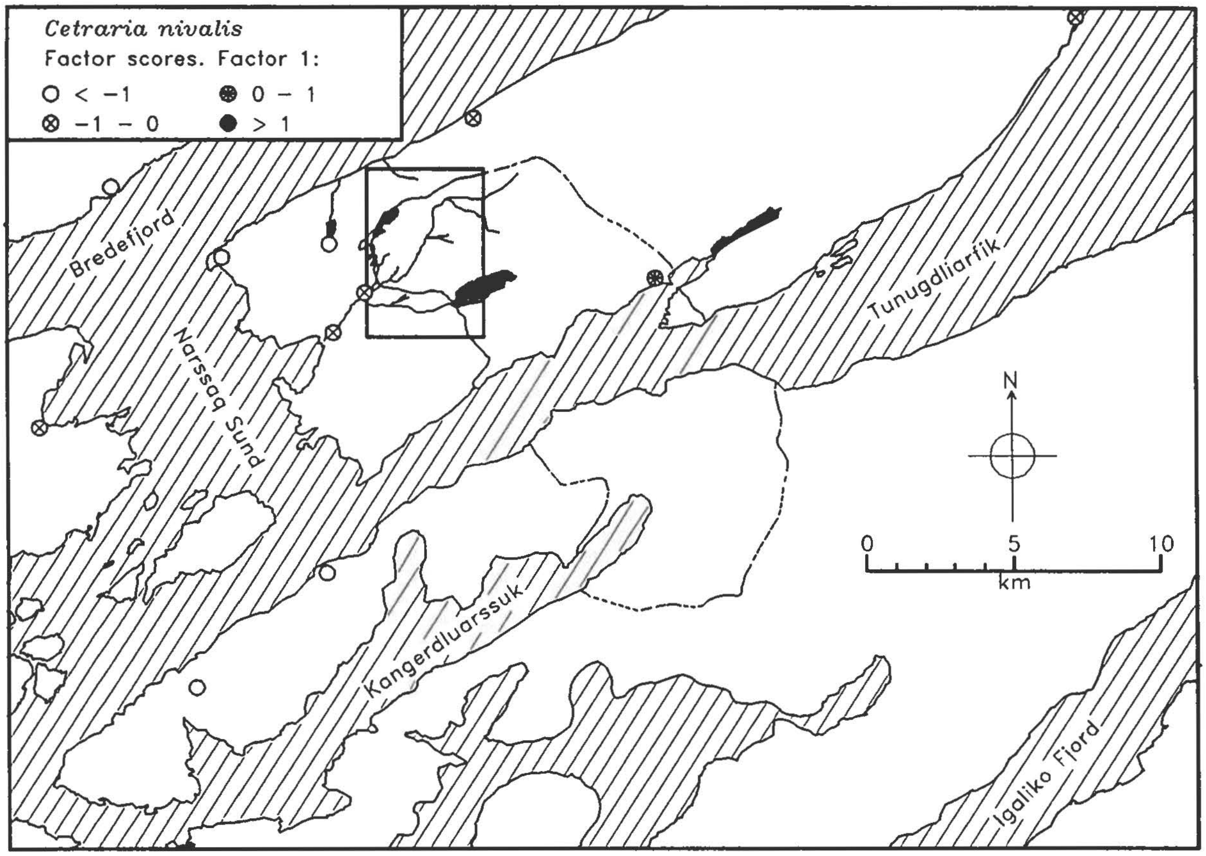

Fig. 10. Factor scores of factor 1 (including the elements characteristic of the intrusion: Sc, Fe, Rb, Cs, La, Ce, Nd, Sm, Eu, Tb, Yb, Lu, Hf, Ta, Pb and Th) in *Cetraria nivalis*. The outlined area is shown in Fig. 11.

by the rate of weathering, the humidity, and the wind speed.

Uptake and retention of elements

The lichens and mosses accumulate the elements by particulate entrapment, ion exchange, electrolyte sorption and processes mediated by metabolic energy (Nieboer *et al.* 1978, LeBlanc & Rao 1974). In this study the dominant source of airborne fallout is weathered material from the rocks and therefore particulate trapment is believed to be the dominating process. The metals might subsequently be dissolved either on the surface or inside the plants.

The washing experiment (Table 6) was carried out in

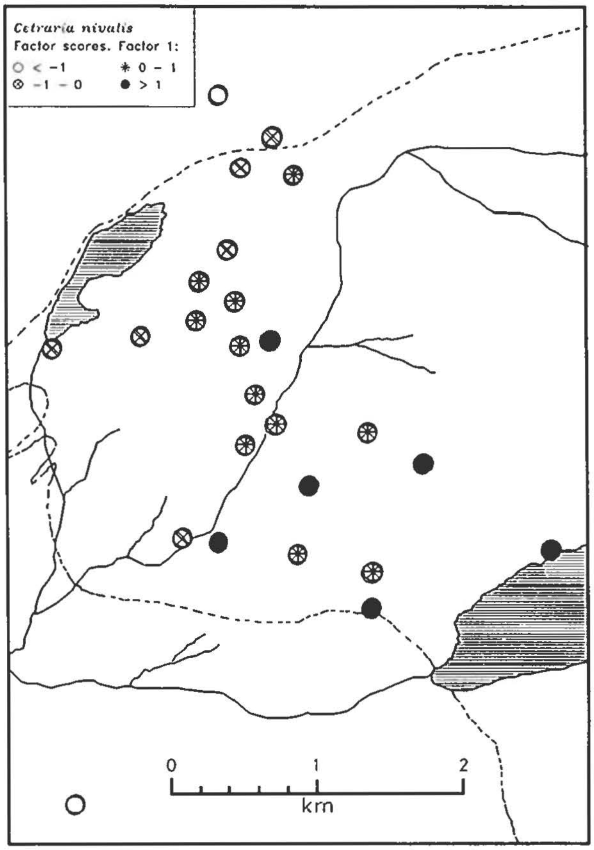

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Fig. 11. Factor scores of factor 1 in *Cetraria nivalis* in the central Kvanefjeld area.

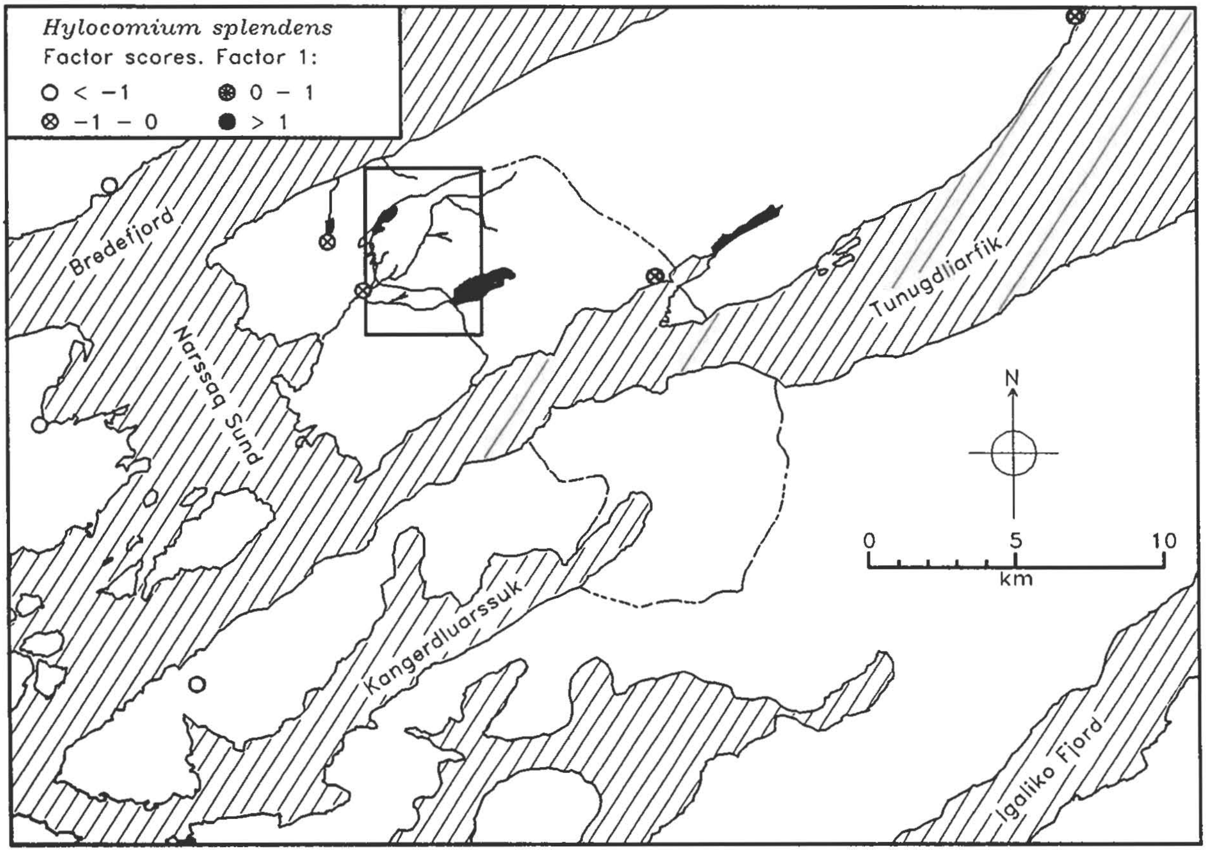

Fig. 12. Factor scores of factor 1 (including the elements characteristic of the intrusion: Fe, Zn, Rb, Cd, Cs, La, Ce, Sm, Eu, Tb, Yb, Hf, Ta, Pb and Th) in *Hylocomium splendens*. The outlined area is shown in Fig. 13.

order to determine the amount of particles trapped attached to the surface of plants. However, there was no difference between washed and unwashed samples of *Hylocomium*, which due to its growth form was thought to be the most efficient filtrator of airborne dusts of the two species applied in this study. This efficiency is probably also the reason why higher concentrations are found in *Hylocomium* than in *Cetraria*. The experiment was, however, carried out on the HNO_3 elutable fraction. Nitric acid might be too weak an acid to dissolve some of the silicate minerals, so it cannot be excluded that such mineral grains are present on the surface of plants. On the other hand the amount extractable with nitric acid is believed to be a better measure of the fraction, which can be accumulated through food chains, than the fraction extractable by total digestion with *e.g.* hydrofluoric acid.

▶

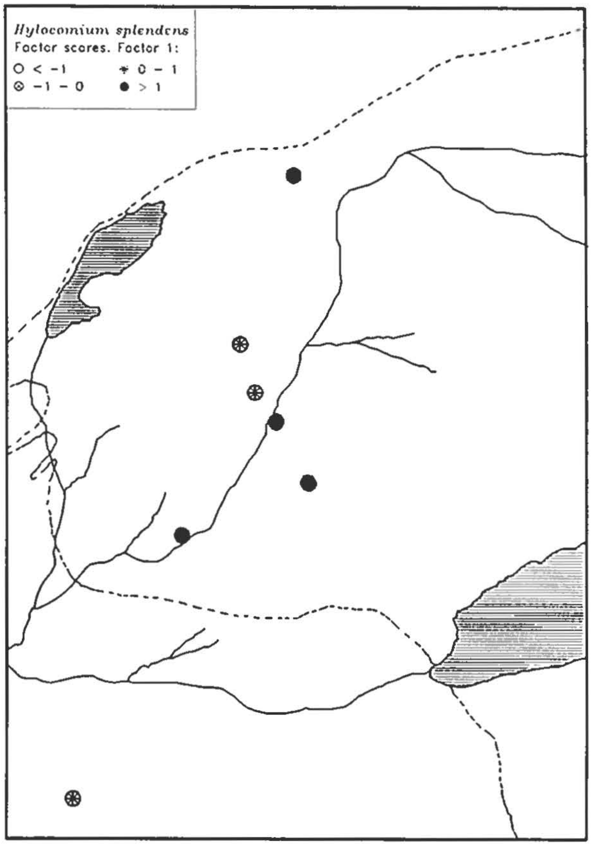

Fig. 13. Factor scores of factor 1 in *Hylocomium splendens* in the central Kvanefjeld area.

Table 11. Summary of mean element concentrations (ppm d.w.) in *Cetraria nivalis* in Greenland and in Northwest Territories, Canada*.

Element	Within intrusion	Outside intrusion	Background Greenland	Northwest Territories
Na	657	546	578	213
K	1626	1505	1643	1434
Sc	0.059	0.040	0.142	0.18
Cr	3.84	5.53	2.76	1.6
Fe	268	134	252	479
Co	0.107	0.098	0.281	0.51
Zn	31.9	15.7	14.4	24.1
As	0.142	0.113	0.178	0.26
Sb	0.068	0.085	0.080	0.08
Pb	10.0	6.1	2.4	4.2

*Puckett & Finegan 1980.

The use of factor analysis

Multivariate techniques have been used in a few studies of biological monitoring of airborne pollutants using lichens and mosses. The subject has been reviewed by Nieboer & Richardson (1981). Principal component and factor analysis methods have been used by Saeki *et al.* (1977), Puckett & Finegan (1977 and 1980), Herrmann & Hübner (1984), de Bruin & Wolterbeek (1984) and de Bruin (1985). The extracted components were rather site specific due to the different pollution sources. Generally it was possible to distinguish a pollution component and a component including soil derived elements. De Bruin calculated an estimate of the contributions of the individual factors to the element concentrations in each sample and depicted the results in geographical maps. This technique is somewhat similar to the calculation of factor scores used in the present study although de Bruin focused on individual elements, while the focus in the present study is on the factor as such.

In the present study the first factor could easily be attributed to the Ilimaussaq intrusion because of the presence of elements occurring in extreme concentrations. The other factors had no relationship to the intrusion. The elements dominating these factors did not occur in higher concentrations in the rocks of the intrusion than in the surrounding rocks, and the geographical distribution of the factor scores were random. Because of the large number of elements enriched in the intrusion it is, however, difficult to define sources for these factors.

Comparison with other samples

In Tables 7 and 8 the element mean concentrations of samples from the Ilimaussaq intrusion are compared with mean concentrations in samples from the immediate surroundings and in samples from several localities in Greenland (background areas). Some elements were found in significantly higher concentrations in the background areas than in the areas within and outside the intrusion. These elements were for *Cetraria:* Sc, Co, Se, Ag, and Hg, and for *Hylocomium:* Se. Other elements were found in higher concentrations in the background areas than in the Narssaq area outside the intrusion. All these elements are probably soil derived and the reason for higher concentrations in the background samples is probably that areas in North Greenland with very scarce vegetation cover are well represented in the background material.

Table 12. Summary of mean element concentrations (ppm d.w.) in *Hylocomium splendens* in Greenland and in Northwest Sweden*.

Element	Within intrusion	Outside intrusion	Background Greenland	Northwest Sweden
Cr	4.6	3.8	6.5	0.7
Zn	202	47	22	47
As	0.48	0.18	0.42	0.16
Cd	0.31	0.15	0.13	0.29
Pb	14.5	6.8	4.1	11

*Gydesen *et al.* 1983

The results from the Narssaq area can be compared with a study of element concentrations in lichens from the Northwest Territories, Canada (Puckett & Finegan 1980) and studies of element concentrations in mosses in Scandinavia (Gydesen *et al.* 1983). Puckett & Finegan analysed 14 lichen species (including *Cetraria nivalis*) from 45 sites for 20 elements by instrumental neutron activation analysis and X-ray fluorescence. Ten elements were identical with those of the present study. A summary of the mean concentrations of these elements in the samples from the Northwest Territories and from Greenland are given in Table 11. Means for samples from Greenland are geometric means whereas the means from the Northwest Territories are arithmetic means. Thus the means from Greenland will probably tend to be lower. Taking this into consideration there is an excellent agreement of the two investigations.

In the Danish and Swedish survey of element concentrations in mosses (*Hylocomium splendens* and *Pleurozium schreberi*) in 1980 more than a thousand samples were analyzed for 8 elements (Gydesen *et al.* 1983). Five elements were identical with those of the present study. The mean concentrations for these elements in *Hylocomium* from Greenland and from Northwestern Sweden are given in Table 12. The anthropogenic derived elements Cd, Pb and Zn are substantially lower in the background samples from Greenland whereas Cr and As are higher, which can be attributed to a higher amount of dust of crustal origin.

Comparison with aerosol measurements

In studies of element concentrations in aerosol samples from various localities in Greenland Heidam (1984 and 1985) has found that by means of factor analysis the atmospheric aerosol can be described by the same 4–5 source related and statistically independent components. The characteristic elements for each aerosol factor were:

Crust:	Al, Si, Ti, Fe, Mn, K, Ca
Marine:	Cl, K, Ca, Br, Sr
Combustion:	Br, Pb, S
Metal:	Cu, Zn
Engine exhaust:	Pb

Calculating crustal enrichment factors and performing a factor analysis on these revealed a simpler and more clear pattern. It was found that the excess (non-crustal) aerosol is composed of three different and statistically independent components that can be related to different sources. The characteristic elements of the factors when the crustal noise was removed were:

General industry:	S, Br, Pb, Cu, Zn
Marine:	K, Ca, Sr, Cl
Ferro-metal:	Mn, Fe

By comparing these results with results of the present study it is seen that none of these factors can be recognized. The explanation for this is probably that several of the elements characteristic of the individual aerosol factors are enriched in the Ilimaussaq intrusion. Otherwise it could be expected that the monitor organisms would show the same source factors as the aerosols.

Acknowledgments

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Appendix

Appendix 1. Element content (ppm d.w.) in *Cetraria nivalis* sampled within the Ilimaussaq intrusion.

							Elements								
Station	Na	K	Sc	Cr	Fe	Co	Zn	As	Se	Br	Rb	Sr	Ag	Cd	Sb
6	465	1640	0.055	7.74	180	0.078	22.4	0.093	0.125	1.41	3.91	13.8	0.17	0.068	
7	729	2130	0.049	9.59	279	0.118	50.1		0.138	1.59	10.70	35.6		0.18	0.066
8	917	1540	0.056	7.57	220	0.164	15.3	0.121	0.159	1.22	2.65	16.9		0.12	0.059
9	353	2220	0.038	9.06	193	0.078	53.1	0.083	0.172	0.99	7.12			0.10	0.043
12	679	1710	0.056	9.68	267	0.126	92.5		0.163	1.34	6.31			0.17	0.211
17	740	2060	0.090	4.85	413	0.122	43.2		0.141	1.85				0.32	0.065
18	790	1960	0.106	2.29	519	0.150	36.5		0.133	2.23				0.13	0.064
21	455	1600	0.054	2.90	175	0.139	22.8	0.118	0.083	1.22	4.58	14.6		0.13	0.060
22	480	1610	0.041	6.33	128	0.237	26.3	0.107	0.062	1.22	2.92	15.9		0.10	0.070
23	1000	1730	0.084	0.98	385	0.099	44.7		0.537	1.07	8.75	23.2		0.20	
24	738	1610	0.053	4.62	326	0.091	27.6	0.294	0.148	1.59	8.25			0.14	0.068
25	606	1670	0.064	3.61	296	0.112	20.9	0.310	0.133	1.39	6.12	9.1		0.14	0.080
26	816		0.130	6.71	600	0.125	38.8		0.203	2.06	11.40	37.7		0.15	
27	855	1710	0.067	3.17	400	0.075	35.1		0.169	1.07	15.50	53.5		0.23	
28	811	1380	0.053	4.20	250	0.085	24.6		0.157	1.43	3.51	25.1		0.33	0.051
31	669	2420	0.062	3.07	466	0.127	96.5	0.133		2.12	18.50	21.2		0.17	0.082
32	436	1820	0.062	3.61	254	0.102	34.9	0.167	0.079	1.95	3.71			0.18	0.074
33	466	1420	0.053	1.05	261	0.088	26.9		0.415	1.42	7.41			0.30	
34	644	1320	0.033	0.78	99	0.050	33.7		0.457	1.16	6.21	72.3		0.28	
41	725	1080	0.041	3.40	137	0.102	19.8		0.188	1.64	4.00	34.9			0.044
42	517	1150	0.053	3.59	236	0.076	21.9		0.140	1.02	8.51	32.3			0.060
43	857	1200	0.060	4.53	398	0.114	23.8		0.150	1.17	6.39	17.1	0.114		0.068
44	946	1530	0.082	3.66	292	0.118	18.0		0.069	2.00	2.29				0.071
$\bar{x}_g$	657	1626	0.059	3.84	267	0.107	31.9	0.142	0.156	1.44	6.08	24.3	0.114	0.17	0.068
s.e.$_g$	1.062	1.046	1.070	1.156	1.100	1.069	1.104	1.170	1.124	1.054	1.132	1.155	1.000	1.088	1.082

Appendix 2. Element content (ppm d.w.) in *Cetraria nivalis* sampled outside the Ilimaussaq intrusion.

							Elements								
Station	Na	K	Sc	Cr	Fe	Co	Zn	As	Se	Br	Rb	Sr	Ag	Cd	Sb
1	743	994	0.086	24.5	277	0.206	11.4	0.119	0.234	1.46	1.19	19.0	0.072	0.11	0.071
2	547	1350	0.039	12.9	139	0.076	13.5	0.132	0.219	0.97	1.23		0.154	0.10	0.066
3	616	2200	0.035	1.53	95	0.054	14.1	0.127	0.396		3.18	12.7		0.10	0.070
4	549	1720	0.037	6.96	122	0.115	15.7	0.126	0.183	1.29	3.66			0.11	0.057
5	462	1600	0.041	6.87	194	0.074	14.0	0.145	0.192	1.72	1.73	5.9		0.10	0.070
10	358	1700	0.045	9.08	133	0.149	17.0	0.130	0.119	1.36	2.55	20.4	0.051	0.20	0.051
11	535	1790	0.042	19.4	155	0.167	21.9	0.112	0.186	1.55	2.80	23.7		0.19	0.181
13	396	1920	0.023	4.31	62	0.074	18.4	0.047	0.106	1.55	3.60	7.5		0.10	0.062
15	663	920	0.027	2.35	126	0.114	11.1		0.344	2.63				0.10	0.853
19	623	1270	0.035	3.34	98	0.112	15.0	0.123	0.088	1.15	2.83	4.4		0.12	0.096
35	530	1400	0.042	2.48	115	0.072	17.8	0.103	0.104	1.41	1.57	21.2		0.16	0.061
36	607	1460	0.034	4.1	124	0.066	25.5	0.116	0.166	1.35	8.16	30.9	0.047	0.16	0.040
38	598	1800	0.063	3.22	219	0.090	13.9		0.530	1.68	3.97	12.2	0.164	0.20	
$\bar{x}_g$	546	1505	0.040	5.53	134	0.098	15.7	0.113	0.191	1.47	2.63	13.4	0.085	0.13	0.085
S.e.$_g$	1.058	1.072	1.097	1.264	1.112	1.117	1.068	1.096	1.163	1.073	1.173	1.228	1.306	1.084	1.265

Appendix 1.

							Elements								
Cs	La	Ce	Nd	Sm	Eu	Tb	Yb	Lu	Hf	Ta	Au	Hg	Pb	Th	U
0.238	8.45	15.9		0.90	0.098	0.071	0.117	0.014	0.069		0.002		7.9	0.973	
3.480	29.5	56.4		2.33	0.196	0.350	0.839	0.116	0.124		0.002	0.041	22.0	7.470	
0.095	2.46	5.5		0.32	0.035	0.030	0.052	0.008	0.096		0.002	0.034	5.6	0.274	
0.353	3.33	7.0		0.66	0.065	0.107	0.242	0.030	0.061		0.002	0.032	5.1	0.947	
0.444	14.4	32.9	20.5	3.61	0.573	1.250	1.510	0.170	0.083	0.070	0.005		12.4	1.500	
0.092	13.9	18.5		1.99	0.151				0.199		0.003	0.031	14.3	0.493	
1.550	20.4	43.6		2.52	0.189				0.310		0.003	0.040	16.1	1.500	
0.081	1.36	3.3	0.8	0.19	0.023		0.035	0.005	0.052	0.024	0.002	0.038	4.5	0.131	
0.113	3.97	8.7	2.8	0.40	0.037		0.064	0.008	0.051	0.027	0.002	0.039	4.5	0.254	
0.587	46.6	65.0	27.1	3.64	0.300		0.469	0.051	0.304	0.210			9.1	1.200	
0.324	27.1	46.4	17.6	3.27	0.225		0.533	0.068	0.203	0.181	0.001	0.030	8.6	0.968	
0.353	16.0	24.7	9.0	1.70	0.122		0.200	0.026	0.163	0.140	0.002	0.030	9.0	0.627	
0.602	64.0	88.5	53.0	10.10	0.779		2.300	0.255	0.718	0.503	0.003		15.5	3.130	
0.492	64.4	79.7	43.4	7.63	0.531		1.850	0.200	0.463	0.261	0.003		14.8	1.930	
0.404	22.6	37.0	15.6	3.00	0.213		0.555	0.069	0.262	0.185	0.003		15.6	0.793	
0.512	18.8	34.5	10.4	1.45	0.105		0.279	0.034	0.134	0.064	0.020		8.7	1.530	
0.087	6.35	12.1	4.1	0.70	0.054		0.123	0.016	0.121	0.067	0.001	0.038	9.6	0.689	
0.373	17.0	31.9	9.5	1.46	0.113		0.199		0.127	0.091		0.062	20.0	0.925	
0.093	8.83	13.9	5.0	0.86	0.075		0.167		0.038	0.025	0.005	0.059	7.8	0.272	
0.175	22.5	19.4	12.0	1.93	0.141	0.189	0.247	0.032	0.096	0.089	0.008	0.032		0.382	
0.397	98.1	98.7	55.1	7.68	0.496	0.701	0.981	0.121	0.232	0.188				0.610	
0.669	48.3	59.2	27.2	4.65	0.292	0.394	0.702	0.087	0.259	0.222	0.001	0.039		2.070	1.320
0.140	8.21	18.1	5.4	0.94	0.111	0.092	0.138	0.018	0.092	0.059	0.003	0.049		1.100	
0.304	15.11	25.3	11.7	1.71	0.145	0.199	0.303	0.040	0.140	0.101	0.003	0.039	10.0	0.863	1.320
1.223	1.257	1.212	1.312	1.240	1.215	1.488	1.290	1.303	1.169	1.238	1.168	1.061	1.119	1.207	1.000

Appendix 2.

								Elements								
Cs	La	Ce	Nd	Sm	Eu	Tb	Yb	Lu	Hf	Ta	W	Au	Hg	Pb	Th	U
0.030	1.74	4.0	1.47	0.28	0.036	0.021	0.053	0.004	0.096	0.033	0.062	0.004	0.034	7.3	0.107	0.207
0.038	1.93	4.0	1.28	0.24		0.025	0.019	0.003	0.035			0.003	0.047	8.0	0.076	
0.063	0.63	1.3			0.012				0.029				0.048	3.8		0.035
0.083	0.78	1.8		0.13	0.016	0.010	0.020	0.002	0.042	0.018		0.003	0.039	4.1	0.047	
0.034	0.72	1.6		0.11	0.014	0.090	0.014	0.001	0.039			0.004	0.043	6.6	0.046	
0.039	1.29	2.9	0.71	0.18	0.022	0.015	0.028	0.004	0.043	0.019		0.002	0.053	8.4	0.081	
0.040	1.73	3.9	1.28	0.25	0.026	0.027	0.048	0.006	0.036	0.015	0.248	0.005	0.065	4.1	0.129	
0.067	0.75	1.5		0.11	0.009		0.015	0.002	0.023			0.002	0.041	5.3	0.043	
0.030	0.43	1.0		0.06	0.008				0.038			0.003	0.033	6.6	0.033	
0.043	0.78	1.7	0.47	0.12	0.015		0.020	0.003	0.031	0.015		0.008	0.034	6.0	0.067	
0.023	1.81	3.6	1.13	0.26	0.030	0.021	0.030	0.004	0.044	0.015		0.010	0.042	8.1	0.082	
0.065	5.11	10.5	2.79	0.54	0.057	0.068	0.083	0.010	0.141	0.029		0.002	0.045	7.9	0.229	
0.091	2.08	4.3	1.38	0.24	0.034	0.022	0.046	0.006	0.044	0.038		0.007	0.064	6.4	0.126	
0.046	1.22	2.6	1.17	0.18	0.020	0.026	0.029	0.004	0.044	0.021	0.124	0.004	0.044	6.1	0.077	0.085
1.126	1.204	1.199	1.205	1.178	1.290	1.258	1.191	1.182	1.145	1.145	2.000	1.167	1.063	1.080	1.174	2.432

Appendix 3. Element content (ppm d.w.) in *Hylocomium splendens* sampled within the Ilimaussaq intrusion.

	Elements													
Stations	Na	K	Sc	Cr	Fe	Co	Zn	As	Se	Br	Rb	Sr	Ag	Cd	Sb
17	1120	4240	0.286	5.61	1450	0.351	102	0.171	0.099	5.40	16.4	31.1		0.21	0.127
23	3890		1.160	6.33	8100	1.190	301			13.30	45.6	63.8	1.470	0.48	
24	1960	3540	0.453	7.62	4090	0.556	144	2.030	0.248	8.61	36.9	47.7	0.148	0.25	0.190
31	988	3390	0.262	5.63	1680	0.304	204		0.133	7.98	29.7			0.16	0.110
32	1060	3830	0.276	1.57	1710	0.359	256		0.751	8.76	24.2			0.52	
34	1600	4430	0.506	3.72	3380	0.840	297	0.315	1.000	14.40	35.5			0.41	0.155
$\bar{x}_g$	1560	3870	0.420	4.55	2790	0.526	202	0.478	0.301	9.24	29.8	45.6	0.466	0.31	0.142
S.e.$_g$	1.237	1.052	1.262	1.263	1.315	1.250	1.194	2.105	1.583	1.158	1.160	1.232	3.152	1.219	1.126

Appendix 4. Element content (ppm d.w.) in *Hylocomium splendens* sampled outside the Ilimaussaq intrusion.

	Elements													
Stations	Na	K	Sc	Cr	Fe	Co	Zn	As	Se	Br	Rb	Sr	Cd	Sb
2	851	2460	0.294	2.35	1220	0.686	19.2	0.196		17.2			0.10	
3	769	3710	0.218	1.90	1050	0.371	41.8		0.671	6.4	7.2	19.2	0.08	0.101
13	686	2790	0.208	5.58	1130	0.664	58.0		0.086	13.0	10.4	66.7	0.27	0.115
15	572	3230	0.157	2.03	745	0.641	26.6		0.466	9.1	8.1	23.8	0.08	0.107
19	1060	4080	0.300	5.48	1450	0.656	82.8	0.147	0.108	10.3	8.2	48.1	0.36	0.082
35	878	3610	0.311	6.21	1510	0.453	103.0	0.190	0.142	6.1	7.6	31.8		0.110
37	2520	4600	0.768	5.14	3510	0.891	63.6			3.7	14.0	51.1	0.15	
38	1850	3200	0.485	4.56	2300	0.577	36.7			13.8	7.5	69.9	0.15	
$\bar{x}_g$	1014	3400	0.304	3.77	1450	0.599	47.2	0.176	0.210	9.0	8.8	42.6	0.15	0.102
S.e.$_g$	1.196	1.074	1.195	1.193	1.186	1.100	1.223	1.095	1.508	1.198	1.095	1.172	1.248	1.061

Appendix 3.

							Elements								
Cs	La	Ce	Nd	Sm	Eu	Tb	Yb	Lu	Hf	Ta	Au	Hg	Pb	Th	U
0.135	4.5	9.2	2.92	0.63	0.073	0.061	0.192	0.028	0.649	0.165	0.003	0.088	11.4	0.49	
1.880	21.0	353.0	152.00	2.27	1.550	2.210	4.210	0.305	6.340	2.880			43.0	16.40	
0.813	50.0	102.0	35.80	3.38	0.415	0.601	1.680	0.225	3.060	1.090	0.004	0.075	21.0	6.72	7.78
0.297	15.5	28.4	8.47	1.26	0.110	0.118	0.151	0.046	0.547	0.247	0.004	0.071	9.6	6.96	1.96
0.227	11.0	19.8	7.31	1.10	0.104	0.123	0.323	0.044	0.705	0.281	0.003	0.108	7.5	1.60	
0.493	28.9	49.8	15.30	2.66	0.246	0.259	0.687	0.108	1.250	0.500	0.004	0.138	12.5	2.82	
0.436	16.9	45.8	15.71	1.61	0.226	0.259	0.598	0.087	1.351	0.512	0.004	0.093	14.5	3.45	3.91
1.472	1.404	1.694	1.762	1.296	1.592	1.706	1.701	1.484	1.494	1.548	1.057	1.130	1.295	1.667	1.992

Appendix 4.

							Elements							
Cs	La	Ce	Nd	Sm	Eu	Tb	Yb	Lu	Hf	Ta	Au	Hg	Pb	Th
0.141	5.18	10.1		0.66	0.092		0.160		0.452	0.115			6.5	0.412
0.072	1.86	4.4		0.28	0.039	0.025	0.093		0.399	0.149	0.003	0.092	7.6	0.261
0.518	22.80	17.4	14.70	2.48	0.219	0.195	0.350	0.046	0.478	0.161	0.014	0.078	5.4	0.396
0.216	3.04	6.1		0.44	0.049	0.032	0.110		0.232	0.048	0.003	0.073	4.3	0.252
0.090	4.26	9.9	3.04	0.56	0.075	0.055	0.169	0.024	0.555	0.171	0.006	0.134	9.9	0.815
0.104	4.53	11.1	3.60	0.69	0.077	0.055	0.155	0.027	0.632	0.158	0.003	0.077	7.8	1.240
0.159	6.27	15.6		0.85	0.142	0.073	0.249		1.200	0.270			9.3	0.931
0.128	6.11	14.0		0.86	0.129	0.076	0.247		1.070	0.342			5.6	1.020
0.147	5.15	10.1	5.44	0.70	0.089	0.059	0.176	0.031	0.555	0.155	0.005	0.088	6.8	0.564
1.242	1.291	1.181	1.648	1.251	1.222	1.286	1.169	1.222	1.207	1.231	1.338	1.117	1.106	1.252

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