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Epilithic Lichen Communities in High Arctic Greenland: Physical, Environmental, and Geological Aspects of Their Ecology in Inglefield Land (78°–79°N)

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Abstract

The present investigation of High Arctic epilithic lichens and their substrate is based on field observations in Inglefield Land, North-West Greenland, mainly in 1999, with subsidiary observations from 1995. Eighteen rock samples, all glacial erratics, were specifically selected on the basis of macroscopic mineralization features such as iron and copper staining, vein and breccia structures, and ore minerals. The samples are representative of the crystalline shield, and their lithologies can be matched with exposures in Inglefield Land. Seven lichen communities are recognized, viz. *Pleopsidium chlorophanum* c., *Xanthoria elegans* var. *splendens* c., *Dimelaena oreina–Physcia caesia–Xanthoria elegans* c., *Xanthoria elegans–Umbilicaria virginis* c., *Orphniospora moriopsis* c., *Porpidia flavicunda* c., and *Tremolecia atrata* c. The studied material on the 18 samples reveals no conspicuous correlation between metal concentrations in the rock samples and the lichen communities and, broadly speaking, it can be stated that the lichens reflect more the properties of the rock surface, such as, for example, nitrogen- and iron-bearing weathering crusts, than the mineralogical composition of the rocks. However, there is a very close affinity between the *Orphniospora moriopsis* community and one variety of syenitic rocks with elevated magnetite and phosphorus.

Introduction

Inglefield Land, our study region between 78° and 79°N, is a High Arctic desert with a cold, dry climate. It is situated in the so-called "High Arctic vegetation belt" characterized by very low vegetation, with stunted scrubs like the arctic willow (*Salix arctica*). Given the generally harsh living conditions, with the sun below the horizon for more than four months a year and with winter temperatures that can drop below –50°C, it is perhaps surprising that Inglefield Land supports a flourishing flora, including lichens. The lichen flora forms part of a minimal vegetation that, apart from the other cryptogamic plants (algae, fungi, and mosses), includes ferns, grasses, sedges of which perhaps the most conspicuous is arctic cotton-grass (*Eriophorum scheuchzeri*), and a variety of flowering plants, including the ubiquitous (for Greenland) saxifrage (*Saxifraga*) family.

Systematic identification of the Inglefield Land lichen flora has been dealt with in a previous paper, and a total of 220 taxa of terricolous, saxicolous, and epiphytic lichens are now known (Hansen, 2002a). Other High Arctic Greenland lichens have been described from, for example, Washington Land, just to the northeast of Inglefield Land (80°–81°N; Hansen, 2001b) and from southern Peary Land around 82°N (Hansen, 1995b; for locations see inset map in Fig. 1). The present investigation dealing with epilithic (rock-based) lichens and their different substrata is a sequel study to that previously carried out 150 km to the south in the Qaanaaq area, Prudhoe Land (Hansen and Dawes 1990). The purpose of the two studies is the same, i.e., to examine the connection, if any, between the nature of the substratum and lichen communities on it. Whereas the 1990 study involved a random selection of rocks types, for example, dolerite, sandstone, gneiss, quartz, and pyribolite, the present study is mainly based on rocks that are variously mineralized. However, an observation from 1995 relating to profuse black lichen growth on particular syenitic rocks, both bedrock and loose material of the surficial cover, is also reported on, although the syenitic rocks are not anomalously mineralized.

The lichen flora of Inglefield Land was investigated in the field by the first author in the summer of 1999 based on four localities (see below and Fig. 1). The lichens from a fifth locality were collected by a botanist colleague, Jon Feilberg. The fieldwork was carried out in connection with a geological mapping program so that response from geologists about the nature of the lichen rock substrate was concurrently offered in the field (Dawes et al., 2000).

In this paper, the physical environment of Inglefield Land is described, including physiography, climate, and location, and reference is made to historical but little-published lichen collections by the early explorers of the 19th and early 20th centuries. Eighteen lichen-bearing rock samples from 1999 form the basis of this study, and they were selected for their macroscopic mineralized character, rather than rock type. The samples show a variety of features, including iron and copper staining, ore minerals seen by the naked eye, as well as veined and brecciated rocks with anomalous amounts of sulfides. Many of the rocks show rusty weathering in brown to reddish colors indicative of oxidation of sulfide minerals with the production of a variety of oxyhydroxide and sulfate minerals. On the basis of the 18 samples, seven lichen communities are discussed with the main focus on physical and geological aspects of epilithic lichen ecology. The lichens identified on syenitic rocks collected in 1995 that are not anomalously mineralized can be fitted into this community scheme.

OTHER PUBLISHED STUDIES ON EPILITHIC LICHENS IN RELATION TO THEIR ROCK SUBSTRATE IN GREENLAND

A number of projects have been carried out on Greenland material from lower latitudes in which the relationships of epilithic lichens to their substrata has been the focus of attention. Nearest geographically is an investigation of lichen communities in the Qaanaaq area some 150 km

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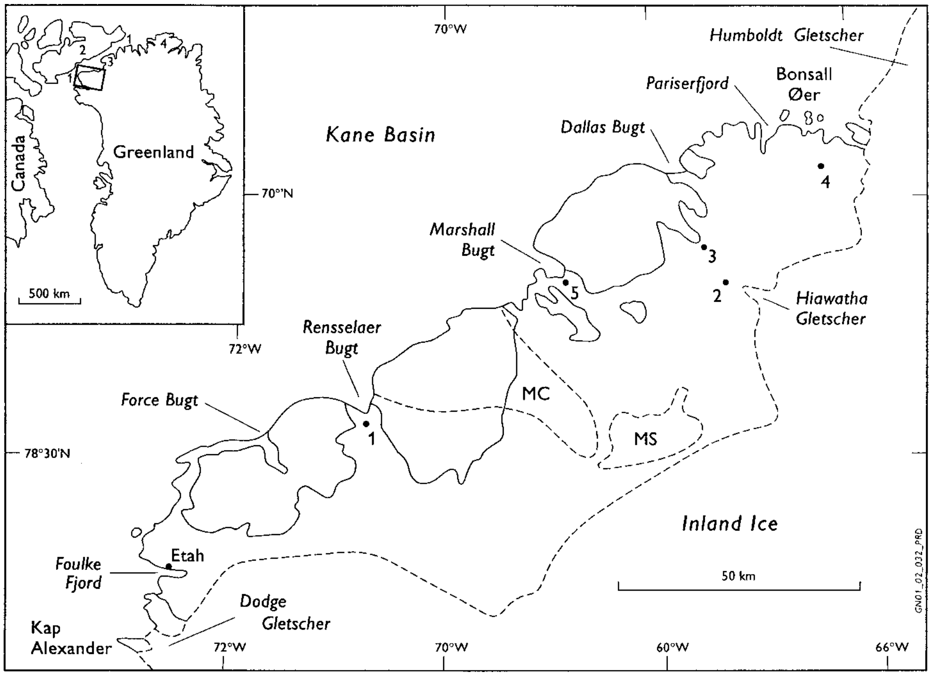

FIGURE 1. Location and geological map of Inglefield Land showing the sample localities from 1999 (1–5). The simplified geology is based on Dawes et al. (2000), with the widespread Quaternary surficial deposits that blanket large areas omitted. Blank areas represent the Paleoproterozoic crystalline shield, with the Minturn syenite body marked MS; stippled ornament is the Mesoproterozoic to Lower Paleozoic sedimentary cover. Letters MS show the fan-shaped distribution of Minturn circles taken from Appel (1996). Inset map: 1—Nares Strait, 2—Ellesmere Island, 3—Washington Land, 4—Peary Land.

to the south (Hansen and Dawes, 1990). The lichen flora there was investigated in relation to selected habitat factors including the mineralogical and chemical composition of the glacial erratic rocks around the town of Qaanaaq. Two communities, viz. an *Acarospora sinopica–Tremolecia atrata* community and a *Dimelaena oreina* community, show obvious relationships to the rock substratum, the former to its mineral composition, and the second to rock hardness.

In 1974, lichen vegetation on a gneissic rock coated with an unidentified copper mineral at Qeqertarsuaq, island of Disko, central West Greenland (69°N) was investigated during which samples of both lichen and substratum were analyzed for contents of selected metals (Alstrup and Hansen, 1977). It was concluded that three species of lichens, viz. *Lecanora polytropa*, *Pseudephebe pubescens*, and *Umbilicaria lyngei*, were able to live on the copper-containing crust, and that they had accumulated high contents (up to 4900 ppm) of this metal. The rock was investigated again in 1996, and a number of additional lichen species were found growing on the green mineral crust (Hansen, 1999).

In connection with biological monitoring of airborne dispersion of pollutants around the alkaline Ilímaussaq intrusion in South-West Greenland (61°N; Pilegaard, 1987) and at the lead-zinc mine at Maarmorilik in central West Greenland (71°N; Pilegaard, 1994), significantly high contents of different metals were proven to occur in the terricolous lichen *Flavocetraria nivalis*. The lichen flora of the latter area has been reported on by Hansen (1991), while Daniels (1975) and Hansen (2002b) have reported on epilithic lichens and their varying substrates in connection with different phytosociological, ecological, and floristic investigations in the Ammassalik District, South-East Greenland (66°N). A number of lichens growing on the mineralogically well-defined Ella Island meteorite from North-East Greenland (73°N) were studied by Hansen and Graff-Petersen (1986).

From the above-cited papers, some understanding of the preferences and tolerances of epilithic lichens to physical environment and rock substrata has emerged. This paper is a contribution to this knowledge.

Physical Environment

LOCATION AND HABITATION

Inglefield Land is a 7000 km^2 ice-free area surrounded by water and ice situated between the central ice sheet of Greenland (Inland Ice) and Kane Basin, the central part of Nares Strait, the seaway separating Greenland and Ellesmere Island, Canada (Fig. 1). Located approximately between 78°–79°N and 65°30′N, 73°W, it stretches from Kap Alexander in the southwest (Greenland's westernmost point) to groups of small islands in the northeast, including Bonsall Øer. Here the mainland is bounded by the Humboldt Gletscher that, with an ice front almost 100 km wide, is Greenland's largest; to the southwest Dodge Gletscher reaches the sea at Kap Alexander and physically separates Inglefield Land from Prudhoe Land to the south.

There are no permanent dwellings in Inglefield Land. The nearest settlement is Siorapaluk in Prudhoe Land, about 60 km to the south; Qaanaaq, capital and largest town of the Thule region, is about 150 km away. A number of abandoned Eskimo villages are located along the coast, and at Foulke Fjord, Rensselaer Bugt, Marshall Bugt, and Pariserfjord, wooden and turf houses are occasionally occupied on hunting expeditions from the south (Fig. 1). In summer these localities, as well as those abandoned in historical time, can be identified from the air by the conspicuous green color of the anomalous vegetation.

EXPEDITIONARY ACTIVITY AND LICHENS

Although the study of Greenland's cryptogamic flora (fungi, mosses, algae, and lichens) did not really gain momentum until around 1900, the first lichens from our study area, Inglefield Land, were collected and reported on already in the 1850s. In the 19th and early 20th centuries, Nares Strait was explored by a series of expeditions (British, American, Norwegian, German, and Danish), and botanical collections of varying size and diversity were made.

In the period 1853 to 1935, no fewer than a dozen expeditions wintered in Inglefield Land, all in the southwestern part between Foulke Fjord and Rensselaer Bugt where the bases could be reached by ship (Fig. 1). Botanical collections, including lichens, were assembled by many of these expeditions, mostly by layman, but occasionally by natural scientists, even botanists, and wintering parties, as well as those passing Inglefield Land en route for the north, sampled the flora (e.g., Durand, 1856; Hayes, 1867; Hooker, 1878; Fries, 1879; Ekblaw, 1918; Wilmott, 1936). The first two expeditions to winter in Inglefield Land, Elisha K. Kane's and Isaac I. Hayes' expeditions in 1853–1855 and 1860–1861, respectively, collected lichens, the taxa being described by Prof. Thomas P. James, with some results being published in the Proceedings of the Academy of Natural Sciences of Philadelphia (Durand, 1856; Hayes, 1867).

A lichen observation made by many expeditions pertains to Foulke Fjord in southwestern Inglefield Land and to Etah, now abandoned, but for many years the largest settlement in the region (Fig. 1). The high, steep, lichen-covered fjord walls particularly east of the settlement, support dense colonies of birds, mainly dovekies (little auk, *Alle alle*) and guillemots (*Uria lomvia*). Thus, the impressive reddish orange colors of these cliffs due to lichen growth (e.g., *Xanthoria elegans*) that thrive on the bird droppings, were often remarked on (e.g., MacMillan, 1918; Shackleton, 1936) and they were studied from a helicopter in 1999 (see later, under "*5*. Orphniospora moriopsis *Community*"). We now know that the rocks forming the steep sides of Foulke Fjord are dominated by orthogneisses of intermediate composition (see later section on "*REGIONAL GEOLOGY AND ROCK LITHOLOGIES*") and that the lichen growth in many places is so dense that the geological structure of the rocks is obscured.

Expeditions led by Donald B. MacMillan, 1913–1917, and E. Shackleton, 1934–1935, wintered at Etah and both collected lichens (Ekblaw, 1918; Wilmott, 1936). W. Elmer Ebklaw, botanist and geologist of MacMillan's expedition, spent four years (three winters) at Foulke Fjord describing the natural conditions of the vegetation and some relations to rock substratum.

The collections made by the Swedish botanist Thorild Wulff during the Danish Second Thule expedition, 1916–1918, also included lichens, but these appear to originate from north of Inglefield Land (Lynge, 1923), while lichens are not mentioned in the comments of the large collections of plants brought back by the Bicentenary Jubilee expedition, 1920–1923 (Ostenfeld, 1925).

CLIMATE AND PHYSIOGRAPHY

Inglefield Land is a High Arctic desert with permafrost, low precipitation, and low ice-melting rates. Summers are short, with the sun being below the horizon at Etah from 24 October to 18 February. Summers are cool, with a July mean of 7°C, but temperatures often reach above 15°C; January to March are the coldest months with an average temperature of –30°C but with temperatures that can drop to below –50°C. The mean annual precipitation is about 12 cm mostly falling as snow. The sea is frozen for most of the year, and open navigable water is restricted to the southwest for a short summer period. In summer, coastal fog is common especially in the southwest, and Foulke Fjord is well known for the very strong winds that funnel down the fjord from the ice; winds of hurricane force can blow for days on end.

Physiographically, Inglefield Land is a vast, cliff-bounded, highland plateau. It is gently inclined seaward from elevations that reach 600 to 700 m a.s.l. near parts of the Inland Ice to the sea cliffs of the outer coast that are between 300 and 400 m high. In effect, the inner part of this plateau represents an exhumed Precambrian peneplain (see following section, "*REGIONAL GEOLOGY AND ROCK LITHOLOGIES*"). Large parts of this plateau represent a featureless landscape covered by a blanket of surficial deposits, mainly by boulder fields and stony glacial till that often display patterned ground. The plateau supports hundreds of shallow lakes and ponds, with the only large lakes occurring near the Inland Ice margin and west of Hiawatha Gletscher, where the chain of lakes (Septembersøerne) occupy a glacier-scoured valley.

Throughout Inglefield Land, colluvial and solifluction slopes are common, while steeper slopes including the spectacular, often precipitous cliffed coasts have scree slopes at their base. In the short summer season melt water flows over the plateau in front of the Inland Ice, finally draining through a number of sizeable rivers that have cut deep valleys on their way to the coast at Force Bugt, Rensselaer Bugt, Marshall Bugt, and Dallas Bugt.

REGIONAL GEOLOGY AND ROCK LITHOLOGIES

The bedrock geology of Inglefield Land is very variable, being composed of two regional provinces of contrasting character with a variety of mineralizations (Schjøth et al., 1996; Thomassen and Dawes, 1996; Dawes et al., 2000). Descriptions of the main mapped rock units are now available (Dawes, 2004). The provinces are a Precambrian (Paleoproterozoic) shield of highly deformed and metamorphic rocks overlain by an unmetamorphosed cover of late Precambrian (Mesoproterozoic) and Lower Paleozoic (Cambrian and Ordovician) age (Fig. 1). In this paper, the former is referred to as "the crystalline shield", and the latter as "the sedimentary cover". The two provinces are separated by a major hiatus during which the old crystalline mountains were severely eroded down into a regular landscape or peneplain, and on which the various strata of the sedimentary cover were deposited in continental to marine environments.

The Crystalline Shield

This is composed essentially of two metamorphic rock suites of different origin, one derived from sediments and the other from igneous rocks. Both show large ranges in composition, thus adding to the wide rock diversity of the shield. The *metasedimentary rocks* are pelitic, semi-pelitic to quartz-feldspathic schists and gneisses (in general terminology called paragneisses) that vary in the ratio of mafic (for example, biotite and graphite) to felsic (quartz and feldspar) minerals. The rocks also contain varying amounts of minerals like garnet, sillimanite, and cordierite as well as ore minerals: the iron oxides, magnetite and hematite, and the iron sulfides, pyrrhotite and pyrite. Conspicuous sequences of marbles and calc-silicate rocks also occur. The *meta-igneous* rocks form large areas intrusive into the paragneisses; they are now foliated to varying degrees and can be referred to as orthogneisses. Hypersthene is the most common mafic mineral in both basic and acidic rocks. The meta-igneous suite ranges in composition from acidic (more than 65% SiO_2) to intermediate (54–65% SiO_2), basic (45–54% SiO_2), and ultrabasic (less than 45% SiO_2). As it happens, the above-cited order also corresponds to their abundance in Inglefield Land. Thus, acidic rocks, represented by granite, monzogranite, syenite, and pegmatite, are common, followed by diorite and quartz diorite (intermediate), with much lesser amounts of amphibolite (basic) and with only minor ultrabasic rocks. In Figure 1, the only rock type singled out is a large syenite body (Minturn syenite) described later and on which black thallus lichens thrive (see under "*5*. Orphniospora moriopsis *Community*").

The Sedimentary Cover

This cover of homoclinal strata forms the outer coastal areas of Inglefield Land and is several hundred of meters thick (Fig. 1). It is composed at the base of a variety of sandstones, often ferruginous and red in color, overlain by pale-colored dolomites and limestones that make up the thickest part of the succession.

The eighteen samples focused on in the present study are all rock types belonging to the crystalline shield (see next section and Table 2). Lichens growing on rocks of the sedimentary cover and collected in 1999 have been described elsewhere, both from Inglefield Land (Hansen, 2002a), as well as from farther north in Washington Land on the northern side of the Humboldt Gletscher (Fig. 1; Hansen, 2001b).

TABLE 1

Details of Inglefield Land lichen localities from 1999.

Number (Fig. 1)	Name[2]	Position	Date of study	Collector[1]
1	Rensselaer Bugt	78°36′N, 70°50′W	19–25 August	ESH
2	West of Hiawatha Gletscher	78°50′N, 67°18′W	29 July–2 August, 14–18 August	ESH
3	"Four Finger Sø"	78°59′N, 67°10′W	3–10 August	ESH
4	South of Bonsall Øer	79°04′N, 66°25′W	11–13 August	ESH
5	Marshall Bugt	78°50′N, 68°50′W	5 August	JF

[1] ESH = Eric Steen Hansen; JF = Jon Feilberg.

[2] Bugt = bay; Gletscher = glacier; Øer = islands; Sø = lake.

Localities

Rock samples with lichens collected in summer 1999 come from five localities, three inland in northeastern Inglefield Land, and two coastal at Rensselaer Bugt and Marshall Bugt (Fig. 1, Table 1). It should be stressed that the positioning of the five localities was not selected with specific geological or physical environments in mind. The botanical fieldwork was carried out as an accessory activity to a geological mapping program and the localities are all opportunistic, being determined by the position of geological camps and traverses pertinent to that program.

In terms of geological province, all five localities are situated in areas where the crystalline shield is exposed, although at three of the localities (1, 3, and 5) cover rocks are close by (Fig. 1). At Rensselaer Bugt and Marshall Bugt cover rocks crop out over large areas northeast and southwest of the bays to form the coastlands. At all localities, glacial erratics of both crystalline shield and sedimentary cover lithologies occur. The five localities shown in Figure 1 represent camp sites from which foot traverses were made, in some cases up to 5 km from the camp. Thus, from the western localities 1 and 5, as well as locality 4, the shoreline could be reached, while from localities 2 and 4, Hiawatha Gletscher and Inland Ice margin could be visited.

Material and Methods

Out of the 220 lichen taxa collected in total during the present investigation, 84 epilithic lichen taxa have been identified. The cover percentage of all epilithic lichens was estimated in selected, homogenous plots in epilithic lichen vegetation, which is considered to be representative for the lichen vegetation on larger rock faces in Inglefield Land (Hansen, 2002a). The degree of covering was estimated using the following modified scale of Hult-Sernander: 5 = 1/2; 4 = 1/2–1/4; 3 = 1/4–1/8; 2 = 1/8–1/16; 1 < 1/16; + = just present. Moisture conditions, rock type, and any occurrence of particular mineral crusts and guano were recorded for the different lichen habitats. The surface examined in analysis of the communities is supposed to have uniform ecological conditions and varies from 50×50 cm to 10×10 cm in size. Exposure and slope of the rock faces were measured, and a distinction was made between top, sloping, vertical, and overhanging surfaces. Dominant lichen species were recorded in all cases, where it was possible.

Three hundred lichen-bearing rock samples were collected in July and August 1999. The investigation of the relationship between rock type and lichen contents is based on 18 rock samples, fist-sized or smaller, that were specifically selected on the basis of macroscopic mineralization features such the presence of iron sulfide minerals and their "rusty" weathering product, limonite (iron hydroxides). All samples are of loose material, i.e., glacial erratic cobbles and boulders that are a common component of the glacial till and glacio-fluvial deposits. All 18 rocks collected are representative of the crystalline shield, and their lithologies can be matched with exposures in Inglefield Land. The rocks, their lichen contents, and the communities they are referred to are listed in Table 2. Some lichens were identified in the field, others in the laboratory, and the nomenclature used follows for the most part Santesson (1993). The collected material is deposited at the Botanical Museum, University of Copenhagen, Denmark.

The chemical analyses of the 18 samples given in Table 3 were obtained by a combination of instrumental neutron activation and inductively coupled plasma emission spectrometry carried out in Ontario, Canada, at Activation Laboratories Ltd.

Lichen-Syenite Affinity

As mentioned earlier under "*REGIONAL GEOLOGY AND ROCK LITHOLOGIES*", granites and other acidic rocks, like syenites and monzogranites, are common in the crystalline shield of Inglefield Land (Schjøth et al., 1996; Dawes et al., 2000; Dawes, 2004). One variety of syenitic rocks cropping out in south-central Inglefield Land (Minturn syenite, marked MS in Fig. 1) is characterized by having an unnaturally dark appearance that is mainly due to profuse black lichens that thrive on rock outcrops, as well as on loose material. The syenite body shows up on the aeromagnetic maps as a distinct magnetic high (Stemp and Thorning, 1995; Schjøth et al., 1996). A main rock type of the syenite body is characterized by elevated content of magnetite and apatite that produce, respectively, the high magnetic anomaly and the high phosphorus content of surrounding sediment and soil (Steenfelt and Dam, 1996). The syenitic rocks are very conspicuous by their varying dark hues conditional on the density of the lichen cover, and some rocks appear simply black with the surface being totally lichen covered. As reported in Appel (1996), the main taxa on syenitic samples collected in 1995 and identified in the laboratory in Copenhagen are *Pseudephebe minuscula* and *Sporastatia testudinea*.

Moraines having a high proportion of boulders and cobbles of this rock type—including the so-called Minturn circles of Appel (1996)—are further accentuated because of the contrast in color with the underlying pale gneisses and carbonate rocks of, respectively, the crystalline shield and sedimentary cover, that do not host such a lichen intensity (Fig. 2). In effect, it was the black color of these features that led to their initial discovery on videos and on aerial photography (Stemp and Thorning, 1995) and later enabled the circles to be spotted in the field on the featureless plateau landscape of central Inglefield Land. It is also safe to say that the mapping of the regional distribution of the Minturn circles, which occur in a belt from the headwaters of the Minturn Elv to the outer coast between Rensselaer Bugt and Marshall Bugt (marked MC on Fig. 1), could not have been undertaken had the circles been composed of glacial erratics of other rock types. This provides an illustrative case where the close affinity between the black thallus lichens and the composition of the syenite has played a very important role in mapping of geological features.

TYPES OF EPILITHIC LICHEN VEGETATION

Seven community types of epilithic lichen vegetation are recognized on the basis of floristic composition, with particular emphasis on dominant species, and different habitat factors, for example, mineral contents of the rocks (in particular their crusts), occurrence of guano, exposure and slope of the rock faces, and influence of moisture, wind, and other climatic conditions. The information collected is primarily based on the 1999 fieldwork and the resulting collections. The observation from 1995 pertaining to black thallus lichens on syenitic rocks fits into the community scheme presented (see below, "*5.* Orphniospora moriopsis *Community*").

TABLE 2

Overview of samples, localities, geochemical enhancement, rock types, lichen taxa, and communities.

Sample no.	Geochemical enhancement	Rock type (field description)	Community (1–7) and lichen taxa	Locality
990562	As	Garnet quartz-rich rock with limonite staining	(1) *Melanelia infumata*, *Ophioparma ventosa*, *Physcia dubia*, *Pleopsidium chlorophanum*, *Rhizoplaca melanophthalma*, *Rhizocarpon geographicum*, *Umbilicaria decussata*, *U.lyngei*, *Xanthoria borealis*	2
990648	S, Al	Paragneiss	(1) *Pleopsidium chlorophanum*	3
990866	none	Biotite quartz schist with limonite and minor sulphides	(1) *Arctoparmelia separata*, *Melanelia disjuncta*, *Ophioparma ventosa*, *Pseudephebe minuscula*, *Rhizocarpon geminatum*, *R. pusillum*, *Sporastatia testudinea*, *Umbilicaria lyngei*	3
990724	none	Fine-grained, pink biotite schist	(2) *Aspicilia aquatica*, *Lecidea tesselata*, *Xanthoria elegans* var. *splendens*	3
990512	none	Orthogneiss with limonite crust + sulphides	(3) *Candelariella vitellina*, *Dimelaena oreina*, *Melanelia disjuncta*, *Physcia caesia*, *Physcia dubia*, *Pseudephebe minuscula*, *Rhizocarpon geminatum*, *R. inarense*, *Umbilicaria vellea*, *Xanthoria elegans*	2
990663	Zn, Ca, Mg, Mn, Fe, Ti, V	Fine-grained orthogneiss with magnetite	(3) *Candelariella vitellina*, *Dimelaena oreina*, *Lecanora dispersa*, *Physcia caesia*, *Xanthoria elegans*	3
991165	none	Fine-grained quartz-rich rock	(3) *Dimelaena oreina*, *Melanelia infumata*, *Physcia caesia*, *Pseudephebe minuscula*, *Rhizocarpon pusillum*, *Rhizoplaca melanophthalma*, *Sporastatia testudinea*, *Umbilicaria decussata*, *Xanthoria elegans*	1
990660	Mn, Al, P, Sr	Rusty orthogneiss with minor ?magnetite	(4) *Lecidea auriculata*, *Pseudephebe minuscula*, *Xanthoria elegans*	3
990751	Mn, Ca, Mg, Fe, Ti, V	Fine-grained amphibolite with minor ?magnetite	(4) *Aspicilia mashiginensis*, *Physcia caesia*, *Rhizocarpon geminatum*, *Umbilicaria virginis*, *Xanthoria elegans*	5
990853	S	Graphitic paragneiss	(5) *Orphniospora moriopsis*, *Pseudephebe minuscula*	3
991011	Au, Ag, Cu, Na, Sr	Chalcocite-bearing orthogneiss with malachite coating	(6) *Lecidea atrobrunnea*, *Porpidia flavicunda*, *Pseudephebe minuscula*, *Rhizocarpon geminatum*	4
990482	S	Paragneiss with graphite-limonite crust	(7) *Acarospora sinopica*, *Lecidea lapicida*, *L. silacea*, *Ophioparma ventosa*, *Pseudephebe minuscula*, *Tremolecia atrata*, *Umbilicaria hyperborea*, *U. lyngei*	2
990665	Cu, Mo, S	Rusty paragneiss with sulphides	(7) *Rhizocarpon geographicum*, *Tremolecia atrata*	3
990699	Pb, Mo, S, K, Ba	Rusty gneiss with limonite and trace of sulphides	(7) *Acarospora sinopica*, *Tremolecia atrata*	3
990703	Th	Microgranite from late dyke	(7) *Lecidea lapicida*, *Pseudephebe minuscula*, *Rhizocarpon geminatum*, *Tremolecia atrata*, *Umbilicaria proboscidea*, *U. virginis*	3
990718	none	Gneiss	(7) *Acarospora sinopica*, *Lecidea tesselata*, *Rhizocarpon geminatum*, *Tremolecia atrata*	3
990741	Ni, Cr	Orthogneiss	(7) *Hymenelia lacustris*, *Miriquidica garovaglii*, *Tremolecia atrata*	3
991016	S	Gneiss with graphite-limonite crust	(7) *Tremolecia atrata*	4

Comparison is made with results from other parts of Greenland and other arctic and alpine areas.

1. Pleopsidium chlorophanum *Community (Samples 990562, 990648, and 990866)*

This community mainly occurs on different siliceous rocks that are partly coated with limonite; apart from this, no particular metal preferences were observed. Wirth (1980) notes the occasional occurrence of *Pleopsidium chlorophanum* on rocks rich in iron in southwestern Germany. Just like the Qaanaaq populations described by Hansen and Dawes (1990), those of Inglefield Land prefer exposed situations such as top surfaces of boulders and cobbles. Here, *Pleopsidium chlorophanum* sometimes occurs in association with different nitrophilous lichens, for example, *Melanelia infumata*, *Physcia dubia*, *Protoparmelia badia*, *Umbilicaria decussata*, and *Xanthoria borealis* (locality 2). *Ophioparma ventosa* is often a member of the association in those sites exposed to the wind. The community is closely related to the *Physcia dubia*–*Xanthoria borealis* community, which, however, more frequently occurs on drier rock faces without traces of limonite. Sometimes, *Pleopsidium chlorophanum* grows solitarily on boulders and rocks faces. The species is characterized by its very low degree of covering in Inglefield Land contrary to its populations in more southern parts of Greenland, where it sometimes is the dominant lichen together with *Xanthoria elegans*, in particular on overhanging rocks.

TABLE 3

Chemical analyses of the lichen-bearing rocks from Inglefield Land.

Sample no.	Al (%)	Ca (%)	Fe (%)	K (%)	Mg (%)	Na (%)	P (%)	S (%)	Ti (%)	As (ppm)	Au (ppb)	Ba (ppm)	Co (ppm)	Cr (ppm)	Cu (ppm)	Mn (ppm)	Mo (ppm)	Ni (ppm)	Pb (ppm)	Sr (ppm)	Th (ppm)	U (ppm)	V (ppm)	Zn (ppm)
990482	6.61	0.40	6.09	4.11	1.26	1.25	0.021	1.016	0.47	2.6	6	1500	10	136	143	100	1	30	26	120	14.0	<0.5	123	139
990512	5.97	1.34	3.53	1.23	0.91	3.15	0.023	0.177	0.19	2.2	5	230	3	45	64	434	<1	5	14	146	13.2	<0.5	40	37
990562	6.22	0.21	6.48	3.72	1.24	1.34	0.028	0.291	0.42	80.3	5	1000	4	129	41	137	<1	6	22	110	17.3	2.5	130	91
990648	7.93	2.26	5.76	1.03	1.37	2.41	0.041	0.407	0.51	2.8	<2	270	2	122	37	388	6	<1	18	189	28.8	4.3	122	126
990660	7.24	4.84	7.88	0.78	2.58	2.95	0.120	0.004	0.53	<0.5	3	460	22	34	29	1514	<1	13	6	433	0.6	<0.5	87	127
990663	6.79	5.74	12.00	0.70	3.27	2.18	0.089	0.005	1.22	<0.5	3	190	53	25	63	2254	<1	33	<3	268	<0.2	<0.5	515	210
990665	4.79	1.44	4.60	2.52	0.85	2.23	0.030	2.343	0.19	<0.5	31	1100	10	23	1237	99	47	26	18	252	5.3	<0.5	59	31
990699	6.45	0.52	4.24	6.31	0.55	2.03	0.022	0.583	0.34	3.6	<2	2600	4	19	59	53	26	9	120	312	5.5	<0.5	49	40
990703	4.53	0.59	1.93	4.24	0.35	2.58	0.038	0.009	0.26	2.1	<2	920	5	12	14	157	3	3	25	111	71.4	4.2	21	46
990718	4.93	1.04	1.97	1.66	0.55	2.38	0.019	0.016	0.23	<0.5	2	520	6	36	13	102	<1	13	13	179	6.4	1.9	37	63
990724	5.31	0.22	2.60	3.16	1.19	2.96	0.027	0.005	0.36	1.9	5	750	7	60	15	120	<1	23	17	167	14.4	1.4	64	37
990741	6.09	0.86	6.11	1.02	2.94	3.00	0.037	0.045	0.40	1.4	<2	420	27	333	13	552	<1	115	<3	163	1.8	<0.5	133	72
990751	6.53	5.68	14.00	0.41	3.48	2.14	0.084	0.048	1.33	1.0	<2	60	54	23	42	2363	<1	15	<3	117	0.5	<0.5	508	145
990853	5.06	2.44	5.92	0.94	0.44	2.10	0.034	0.464	0.16	3.3	<2	200	3	13	72	99	6	<1	20	87	14.3	4.2	53	36
990866	5.46	1.40	3.47	1.27	1.46	1.99	0.020	0.070	0.53	1.1	5	430	8	132	28	244	2	7	12	227	14.0	4.1	117	102
991011	6.74	2.90	3.80	1.59	1.06	3.82	0.007	0.147	0.05	0.8	2930	510	42	80	10104	486	1	83	49	456	0.4	<0.5	51	55
991016	5.28	0.51	5.77	3.30	0.74	1.88	0.033	1.978	0.09	1.5	13	700	5	74	141	124	7	29	31	130	27.6	4.2	62	165
991165	1.05	0.14	0.42	1.38	0.05	0.07	0.025	0.009	0.03	1.9	3	410	<1	18	25	31	1	2	6	33	1.6	0.8	7	4

In North-West Greenland, the species appears to avoid overhangs, while this is the usual substrate for it elsewhere, for example, South-West and South-East Greenland (Hansen, 1978a, 1978b) and also in North America according to Thomson (1997). The High Arctic populations of *Pleopsidium chlorophanum* all have thalli consisting of comparatively few, warty areoles. They possibly belong to a separate taxon adapted to more severe climatic conditions, and they certainly need to be studied further.

An association with *Ophioparma ventosa* and *Arctoparmelia separata* and a number of more or less nitrophilous lichens, for example, *Melanelia disjuncta* and *Rhizocarpon geminatum*, were found at locality 3 on an exposed siliceous rock with traces of limonite and sulfides (sample 990866). The habitat of this association is very similar to that of the *Pleopsidium chlorophanum* community and it occurs close to a well-developed population of this species.

2. Xanthoria elegans *var.* splendens *Community (Sample 990724)*

Xanthoria elegans var. *splendens* (syn. *X. subfruticulosa*) is a rare arctic lichen, which has been reported from North America, Greenland, and Russia (Andreev et al., 1996; Thomson, 1997; Hansen, 2002a). The species occurs, often abundantly and as the dominating lichen species, on different siliceous rock exposures and cobbles that usually have traces of limonite. It is a very conspicuous lichen with its reddish orange, subfruticose thallus, typically growing in temporarily moistened riverbeds (locality 3) and on more or less sloping seepages (locality 4). The species forms a characteristic association with lichens such as *Lecidea tesselata* and *Rhizocarpon geminatum*. The community is probably favored by nitrophilous matter, which often concentrates in riverbeds and along meltwater streams. In North and North-East Greenland, *Xanthoria elegans* var. *splendens* sometimes cover the entire bottom of riverbeds, which are occasionally inundated (e.g., Romer Sø; Alstrup et al., 2000). No special metal preferences by these species are obvious in our collection, but it has previously been shown that *Xanthoria elegans* var. *elegans* has a preference for different iron compounds (Hansen and Graff-Petersen, 1986; Hansen, 1999).

3. Dimelaena oreina–Physcia caesia–Xanthoria elegans *Community (Samples 990512, 990663, and 991165)*

This community, dominated either by *Dimelaena oreina*, *Physcia caesia*, or *Xanthoria elegans*, was recorded on south-facing, vertical and strongly sloping rock surfaces and boulders of a variety of siliceous rock types (localities 1, 2, and 3). Wirth (1972) has previously reported on the preference of *Dimelaena oreina* for strongly sloping rock faces. The species is usually found just below the upper rock surface where the influence of guano from ravens and other birds is great. *Dimelaena oreina* is sometimes the dominant species on apical rock faces. Patches of limonite often occur on those rock faces, which often are moistened by percolating water. However, in North America the species generally occurs on sunny, dry rock faces (Thomson, 1997; Brodo et al., 2001). The community is comparatively rich in nitrophilous lichens such as *Melanelia disjuncta*, *M. infumata*, *Physcia dubia*, *Rhizoplaca melanophthalma*, and *Umbilicaria decussata*. *Umbilicaria vellea* grows abundantly in the moistest places on these rocks.

A somewhat similar association consisting of species such as *Aspicilia candida*, *Caloplaca castellana*, *Dimelaena oreina*, *Phaeophyscia sciastra*, and *Xanthoria elegans* was found on glacial cobbles on low-lying plains near the sea at locality 1. It is probably influenced by guano from different sea birds. The above-mentioned associations differ from the *Dimelaena oreina* community previously described from Qaanaaq (Hansen and Dawes, 1990) by the generally more moist habitat conditions. The statement made in that paper that the *Dimelaena oreina* community at Qaanaaq shows a clear preference for durable rock substrates does apply to some extent to the *Dimelaena* community with *Physcia* and *Xanthoria* in Inglefield Land. An important member of the community, viz. *Sporastatia testudinea*, generally prefers hard rock surfaces. Sample 990663 is high in especially iron, magnesium, calcium, and manganese, but these metals are probably of little or no importance to the lichens.

4. Xanthoria elegans–Umbilicaria virginis *Community (Samples 990660 and 990751)*

This community shows a distinct preference for southerly facing exposures and strongly sloping surfaces of dark, often limonite-coated siliceous rocks with a comparatively high radiation absorption capacity (localities 2, 3, and 5; Figs. 3 and 4). The rocks are magnetic and have high contents of iron in the form of magnetite. The rock surfaces are commonly manured by birds, for example, ravens, and accordingly host nitrophilous lichens, such as *Physcia caesia* and *Rhizocarpon geminatum*. The community is closely related to the *Xanthoria elegans–Physcia caesia* community that occurs to the south at Qaanaaq (Hansen and Dawes, 1990) but differs in the more abundant occurrence of *Umbilicaria virginis*. However, the thalli of this latter species are small in comparison with, for example, the thalli of *Umbilicaria vellea* in the somewhat moister *Dimelaena oreina* community. Generally *U. virginis* appear to have a somewhat lower degree of covering than *Xanthoria elegans*, which often is the dominating species in their habitats. An interesting association consisting of *Melanelia infumata*, *Parmelia sulcata*, *Physcia caesia*, *Umbilicaria decussata*, *U. virginis*, *Xanthoria elegans*, and *X. borealis* was found on gneissic boulders manured by the Greenland gyrfalcon (*Falco islandus*) at locality 1 (Hansen, 2002a). Extremely large *Xanthoria elegans* communities were observed in 1999 from a helicopter on the historic and extensive bird cliffs east of Etah, and also 60 km south of Inglefield Land at Siorapaluk (Fig. 1). These rocks are influenced by guano mainly from little auk. The presence of these and other lichen-covered bird cliffs in the region is not fortuitous since about 80% of the world's population of this particular bird occurs in the Qaanaaq/Thule area (Boertmann, 2001). Both Thomson (1984) and Brodo et al. (2001) mention the typical occurrence of *Xanthoria elegans* on enriched bird-perch rocks in North America. However, these authors also state its very broad substrate amplitude, which includes rocks composed of limestone, old bones, and wood. In Greenland, *X. elegans* is also able to bind gravel and soil particles.

5. Orphniospora moriopsis *Community (Sample 990853); Figure 5*

This community consists predominantly of lichens with a black thallus such as *Orphniospora moriopsis*, *Pseudephebe minuscula*, and *Sporastatia testudinea*. It was recorded in 1999 on cobbles and boulders of varying rock types that have distinct crusts composed of graphite, limonite, and sillimanite. The community is particularly frequent at locality 2. In addition, in 1995, the community was found to thrive on certain syenitic rocks in central Inglefield Land that are enriched in magnetite and phosphorous. *Orphniospora moriopsis* is a widely distributed, circumpolar, arctic-alpine to boreal lichen (Hansen, 1995a). Contrary to, for example, *Dimelaena oreina*, which also grows on sunny, exposed rocks, *Orphniospora moriopsis* is comparatively rare in northern parts of Greenland. In 1996, the first author recorded the species on some gneissic rocks coated with an (unidentified) copper-containing mineral near Qeqertarsuaq, central West Greenland on the island of Disko (Hansen, 1999). Here it grows in an association with, for example, *Acarospora smaragdula*, *Bellemerea alpina*, *Miriquidica atrofulva*, *Sporastatia testudinea*, and *Umbilicaria decussata*. Part of these rocks is coated with iron hydroxides.

FIGURE 2. A Minturn circle composed of syenitic erratics conspicuous in the patterned block field in central Inglefield Land. The surficial black color, caused by lichens of the *Orphniospora moriopsis* community, stands in stark contrast to the pale color of the other glacial erratics (granites and gneisses). Arrow at bottom left shows person for scale.

The rusty-red glacial erratics collected in 1999 hosting these taxa are enriched in sulfur (Table 3), while the surrounding bedrocks, rich in biotite and pyrite, are less resistant, and they commonly crumble and break down into debris (fig. 3). The lichens clearly avoid such pyritiferous rocks, probably due to both the formation of sulfuric acids and the soft nature of the weathering products. During the disintegration of the rocks, iron is liberated and subsequently with rain and meltwater transported to stones situated in depressions some distance away from the pyritiferous rocks (cf. community 7). The lichen flora occurring on cobbles and boulders are often strongly influenced by different iron compounds. The Inglefield Land taxa are included on the list of lichens that have been reported on rust-stained rocks rich in iron, such as that compiled by Purvis and Halls (1996).

6. Porpidia flavicunda *Community (Sample 991011)*

This community was found at locality 4 on a slightly moist gneissic rock coated with malachite (hydroxyl-bearing copper carbonate) and manured by birds. *Porpidia flavicunda* is associated here with *Pseudephebe minuscula* and the two nitrophilous lichens, *Lecidea atrobrunnea* and *Rhizocarpon geminatum*. The association is of particular interest, not only because of the high concentration of copper of the rock substratum (10,104 ppm; see Table 3) caused by the mineral chalcocite and its weathering product malachite, but also because of the occurrence of gold (2930 ppb). Our rock sample is from

FIGURE 3. Iron-rich, yellowish stones totally without lichens and (upper right) dark red, rounded, limonite-coated siliceous rocks, the typical habitat for the *Xanthoria elegans–Umbilicaria virginis* community. West of Hiawatha Gletscher.

a small rock hillock covered by the following soil crust lichens: *Acarospora schleicheri*, *Caloplaca tominii*, *Catapyrenium cinereum*, *C. lachneum*, *Diploschistes muscorum*, *Phaeorrhiza nimbosa*, *P. sareptana* var. *sphaerocarpa*, *Psora vallesiaca*, *Rinodina mniaraea*, and *Toninia sedifolia*. These species, most of which occur more or less commonly on steppe-like soils in Greenland (Hansen 2000, 2001a), have a special preference for the south-facing side of the hillock, where the radiation influx is greatest.

The degree of covering of *Porpidia flavicunda* is comparatively low at locality 4 south of Bonsall Øer compared with that found in more southern areas in Greenland, where it occurs on rocks and boulders over trickling water, often in connection with melting ice. This type of occurrence of the species has also been reported from North America (Thomson, 1997). In South-East Greenland, *Porpidia flavicunda* grows on charnockitic rocks (basic rock varieties rich in hypersthene [Mg, Fe] SiO_3) covered by a thin layer of limonite (Hansen, 2002b). On the island of Disko Island, central West Greenland, *Porpidia flavicunda* occurs together with, for example, *Lecidea lapicida*, *Porpidia melinodes*, and *Tremolecia atrata* on moist basaltic boulders and rocks composed of basalt breccia. The iron content of the basaltic rocks near Qeqertarsuaq on Disko is rather high (12–16 wt.% Fe_2O_3 (Larsen and Pedersen, 1990).

7. Tremolecia atrata *Community (Samples 990482, 990665, 990699, 990703, 990718, 990741, and 991016)*

A number of different associations dominated by *Tremolecia atrata* belong to the *T. atrata* community. They occur on rock faces with strongly varying exposition and slope in a rather moist environment. The degree of covering of *Tremolecia atrata* is often comparatively high compared with that of, for example, *Acarospora sinopica*. One association stands out by its content of additional rust-colored species such as *Acarospora sinopica* and *Lecidea silacea*; this thrives on rocks

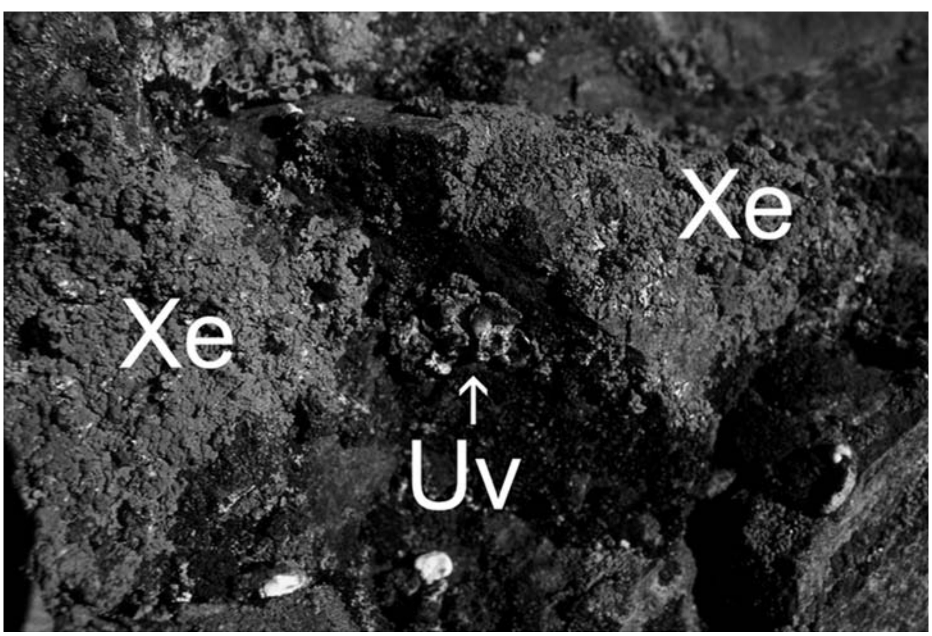

FIGURE 4. Two large thalli of *Xanthoria elegans* (=Xe) and some small thalli of *Umbilicaria virginis* (Uv). West of Hiawatha Gletscher.

FIGURE 5. Gneissic boulders with an open vegetation of epilithic lichens belonging to the *Orphniospora moriopsis* community. Hiawatha Gletscher is in the background.

moderately rich in iron (Creveld 1981; Schwab, 1986). Sometimes macroscopic sulfides are present, for example, in sample 990699. The iron content varies from 2% to more than 6%. The surface of the rock substratum is usually coated with limonite and graphite and accordingly has a reddish brown to dark brown color (samples 990482, 990699, and 990718). The host rocks are different types of gneisses. At locality 3, *Tremolecia atrata* forms an characteristic association with, for example, *Acarospora sinopica*, *Lecidea tesselata*, and *Xanthoria elegans* var. *splendens* on a stony plain, but in many cases *Tremolecia atrata* grows alone or together with, for example, *Rhizocarpon geographicum* on cobbles and boulders enriched in copper, molybdenum, and/or sulfur (cf. samples 990665 and 991016). *Tremolecia atrata* is sometimes associated with more or less nitrophilous lichens such as *Rhizocarpon geminatum* (sample 990718), and along streams it occasionally grows together with *Hymenelia lacustris* (sample 990741).

Microlichens with an ochraceous and rusty thallus, such as *Porpidia flavicunda*, *P. melinodes*, *Tremolecia atrata*, and *Miriquidica atrofulva*, are widely distributed on more or less moist, siliceous rocks in more southern parts of Greenland (Hansen, 1997, 1999, 2002b). These lichens form different associations, which in many ways can be compared with the above-mentioned *Tremolecia atrata* community, although they often are richer in species. A community occurring on vertical, north-facing rock faces at Qeqertarsuaq on the island of Disko represents a typical example. It contains species such as, for example, *Amygdalaria panaeola*, *Bellemerea alpine*, *Lecanora chloroleprosa*, *Miriquidica atrofulva*, *M. nigroleprosa*, *Tremolecia atrata*, and *Vestergrenopsis isidiata*. *Rhizocarpons* such as *R. inarense* and *Umbilicarias*, for example, *U. torrefacta*, are "faithful" members of the association, both in West and East Greenland and in other parts of the Arctic as well. Contrary to the localities of *Tremolecia atrata* in Inglefield Land, its habitats at Qeqertarsuaq are very poor in sulfur ($<0.1\%$), but they usually have very distinct limonite crusts (Hansen, 1999). According to Purvis and James (1985), *Acarospora sinopica* has a distinct preference for exposed, horizontal rocks faces rich in ferrous sulfides. This presumably explains its occurrence in Inglefield land and the apparent lack of the species in the Qeqertarsuaq area of central West Greenland.

Conclusions

The epilithic lichen vegetation of Inglefield Land is readily comparable to the lichen flora at the coastal locality of Qaanaaq, 150 km to the south, both from the point of view of rock coverage density (abundance) and from the number of species present. As might be expected from its High Arctic location and severe climatic conditions, the lichen flora of Inglefield Land is relatively simple, with fewer species than epilithic lichen floras from areas in southern Greenland and elsewhere south of the Arctic Circle.

As regards the correlation between metal concentrations and lichen taxa, a main conclusion must be that no strikingly obvious correspondence is shown by our results. However, "ferruginous" lichens with a rust-colored thallus such as, for example, *Acarospora sinopica*, *Lecidea silacea*, and *Tremolecia atrata* are more dependent on the superficial limonite crusts on the rocks than on the mineralogical composition of the rocks themselves.

The most conspicuous preference found was by lichens of the *Orphniospora moriopsis* community for a variety of syenitic rocks with anomalously high magnetite and phosphorous, an alliance so strong that the lichens proved to be an important tool in geological mapping. Manuring of the rocks by birds also influences the lichen flora in Inglefield Land just as in other parts of Greenland.

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ERRATUM

Epilithic Lichen Communities in High Arctic Greenland: Physical, Environmental, and Geological Aspects of Their Ecology in Inglefield Land (78°–79°N). Eric Steen Hansen, Peter Robert Dawes, and Bjørn Thomassen 38(1): 72–81.

On page 73, replace Figure 1 and its caption with the following:

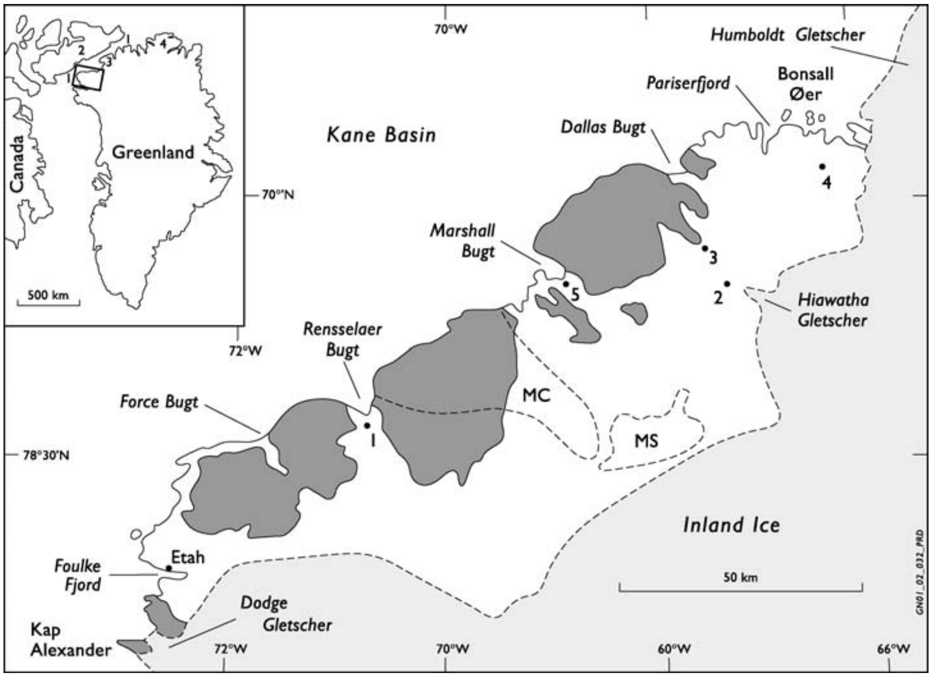

FIGURE 1. Location and geological map of Inglefield Land showing the sample localities from 1999 (1–5). The simplified geology is based on Dawes et al. (2000), with the widespread Quaternary surficial deposits that blanket large areas omitted. Blank areas represent the Paleoproterozoic crystalline shield, with the Minturn syenite body marked MS; dark shading marks the Mesoproterozoic to Lower Paleozoic sedimentary cover; light shading shows the ice cover. MC marks the fan-shaped distribution of Minturn circles taken from Appel (1996). Inset map: 1—Nares Strait, 2—Ellesmere Island, 3—Washington Land, 4—Peary Land.