カナダ北極圏エルズミア島における植物群落型の分化と土壌条件

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Satoru Kojima : Differentiation of plant communities and edaphic conditions in the High Arctic environment, Sverdrup Pass, Ellesmere Island, Canada

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Abstract

Plant communities of Sverdrup Pass area, Ellesmere Island, Canada, were classified on the basis of 57 relevés. Six plant community types were distinguished in relation to soil conditions : 1) *Saxifraga oppositifolia* type occurring in xeric and moderately alkaline habitat, 2) *Saxifraga tricuspidata* type in xeric and, mildly alkaline habitat, 3) *Dryas integrifolia-Salix arctica* type occurring in mesic and mildly alkaline habitat, 4) *Cassiope tetragona* type occurring in mesic and slightly acidic habitat, 5) *Alopecurus alpinus* type occurring in hydric and mildly alkaline habitat, and 6) *Carex aquatilis* ssp. *stans* type occurring in hydric and very slightly acidic habitat. Under the High Arctic climate, soil moisture seemed to be one of the prime factors of the vegetation differentiation. Majority of soils was alkaline reflecting extensive occurrences of calcareous bedrocks and derived substrates, and low leaching rates due to low precipitation.

Key words : High Arctic, soil moisture, soil temperature, vegetation classification.

Introduction

The landscape of the High Arctic, basically a polar desert, is characterized by extremely low, less than 5% in most instances, plant cover (Bliss 1977). Because of the typical paucity of its vascular flora and the relatively broad ecological amplitudes of the species, arctic vegetation classification is difficult and possibly even unrealistic (Griggs 1934 ; Savile 1960). Nevertheless, at some isolated Arctic locations, lusher vegetation has developed and these sites have been identified as a polar oasis (Freedman et al. 1983 ; Svoboda 1990). Such occurrences can be related to prevailing local environmental conditions such as a locally ameliorated climate and an adequate water supply.

Since the 1970 s, an increasing number of plant ecological studies have been carried out in the High Arctic of North America. Those studies have been thoroughly reviewed and summarized by Bliss (1977), Chapin et al. (1992), and Svoboda and Freedman (1994). In recent years, syntaxonomical studies have been conducted in the Arctic, and those were reviewed and summarized by Walker et al. (1994). In 1997, a special issue dealing specifically with the international tundra experiment (ITEX) was published as a supplement of the Global Change Biology (Henry 1997).

In the present study, plant communities were examined and classified in relation to edaphic conditions at Sverdrup Pass, Ellesmere Island, in the Canadian High Arctic. This area was chosen because the plant community was well diversified along different edaphic conditions. The results of this study provide a basis to interpret vegetation patterns in relation to the edaphic conditions.

Study area

The study area is located in Sverdrup Pass (Lat. 79° 08' N, Long. 80° 30' W), Ellesmere Island, Northwest Territories, Canada (Fig. 1). Its elevation is approximately 300 m above sea level and situated at the bottom of a broad ice-free glacial valley. Terrain configuration of the area

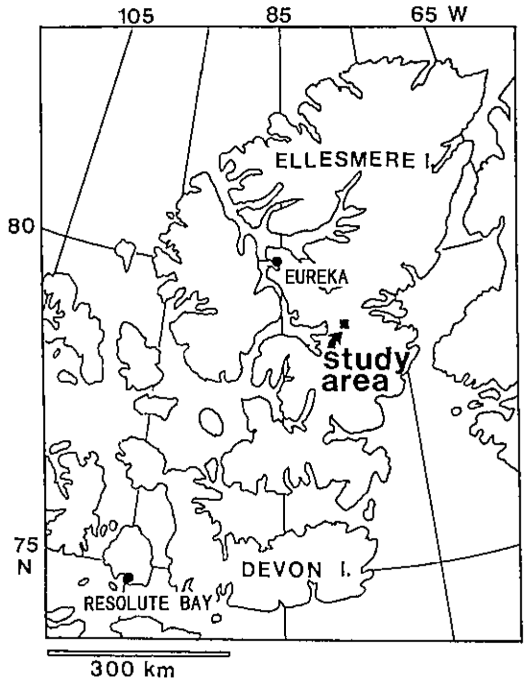

Fig. 1. A map of the study area. It is located in the heart of the Canadian High Arctic.

is represented by a large glacial valley, 1 to 2 km wide with steep sidewalls. The valley extends in a general east-west trend and serves as a corridor connecting the east and west coasts of the island. Above the sidewalls of the glacial valley, which are roughly 400 to 500 m high, there are plateaus covered by ice sheets.

The climate of the area, as interpreted from data recorded by a weather station at Eureka, Alexandra Fiord, and the one locally maintained since 1986, is extremely harsh. Such a climate may be classified as ET after Köppen (1936). Climatically, the study area belongs to the Northern Region and Axel Heiberg and Ellesmere Islands Highlands Subregion (Vc) of Maxwell (1981), with mean daily temperature of January −28 to −32℃, that of July 0 to 3℃, and mean annual total precipitation slightly above 200 mm. July temperatures at the Sverdrup Pass area are, however, 4–10℃ higher than at Eureka and Alexandra Fiord (cf. Labine 1994). Winter season begins in early August. Snowfalls occur at any time during summer. Ryden (1977) estimated an annual total water loss of 101 mm from terrestrial surface for the Truelove Lowland, Devon Island. Levesque et al. (1997) reported mean annual total precipitation 82.5 mm for a five-year average at Sverdrup Pass, of which roughly 52% comes in summer season (June-August).

Geology of the area is dominated by dolostone of the Upper Ordovician and Lower Devonian with sporadic occurrences of granitic gneiss of the Canadian Shield (Thorsteinsson and Tozer 1970). Soils in the valley are generally coarse and highly calcareous, while there are some acidic on the south granitic slopes. Horizon development is poor due primarily to comparatively intense physical weathering, instability of substrates, and relatively young stage of development after deglaciation (7000 years B.P.). Soils are mostly classified as Regosolic Turbic Cryosols and Regosolic Static Cryosols in the Canadian soil classification system (Canada Soil Survey Committee 1978). Such soils are comparable to polar desert soils of Tedrow (1966, 1977) and Charlier (1969). In wet sedge meadows, Gleysolic Static Cryosols develop. Muc et al. (1994) studied soil characteristics at Alexandra Fiord and reported they were generally slightly to moderately acidic.

On average, vascular plant cover is less than 10% in the valley, characteristic for the polar desert landscapes. Vascular plants occur sporadically and most form cushions and compact patches. The three dominantly occurring species include *Salix arctica, Saxifraga oppositifolia*, and *Dryas integrifolia*, which combine to various degrees. In wet habitats, however, exceptionally lush growth is evident as in the case of sedge meadows in valley bottoms, floodplains, and stream edges with *Carex aquatilis* var. *stans* as the principal dominant and *Eriophorum triste* a codominant. In such habitats, plant cover may attain 100%.

Methods and procedures

The field investigation was conducted from mid-July to mid-August, 1991. After an initial reconnaissance of the plant communities, vegetation sampling was carried out. A 5 x 5 m relevé was used as a sampling plot to describe the structure of each plant community. Only homogeneous stands in plant distribution and edaphic conditions were selected for the relevé site. At each site, general environmental conditions such as elevation, slope, aspect, and landform were recorded. Plant cover of each vascular species was subjectively estimated using Domin-Krajina cover classes (Krajina, 1933) as : + (less than 1%), 1 (1–2%), 2 (2–3%), 3 (3–5%), 4 (5–10%), 5 (10–20%), 6 (20–33%), 7 (33–50%), 8 (50–75%), 9 (75–99%), 10 (100%). For cryptogams (bryophytes and lichens), a composite total coverage was assessed and specimens were collected for identification and reference. A total of 57 relevés were established.

At each relevé site, a soil pit was dug to the depth of the rooting zone or permafrost table, or lithic contact whichever was shallower and profile features were described. At the pit, soil temperature was measured, at the time of soil investigation, by the use of a thermistor thermometer (Sato Delta Digital Thermometer SK-1250) at the depths of 0, 2, 5, 10, 20, and 30 cm, if possible, from the surface. Soil moisture was rated subjectively in three broad classes, i.e., xeric, mesic, hydric, based on soil profile features in the field conditions. At some selected twenty sites, soil samples from the top 10–15cm depth where most of the roots were concentrated were collected for measuring soil pH. The samples were air-dried and sieved through a 2 mm screen. Soil pH was measured by a glass-electrode pH meter for 1 : 5 soil-water suspension.

At the Sverdrup Pass base campsite, data logger sensors (Kadec U) were installed to record air (at 2 m from the ground surface) and soil sub-surface (at 2 cm below the surface) temperatures simultaneously in 30-min intervals during the field season. The soil temperature probe was buried below the litter layer of a small *Dryas integrifolia* cushion.

All plant specimens were determined and cross-checked against the field records. Following the phytosociological technique, all the relevés were assembled and subjectively categorized into plant community types which were comparable to plant associations of Braun-Blanquet (1964). Species constancy classes (I to V) were determined for all the plant community types as class V : occurring in more than 80%, IV : 79 to 60%, III : 59–40%, II : 39–20%, I : less than 19% of the total number of the relevés.

Vegetation similarity indices among the relevés were calculated according to Sφrensen's (1948) method as modified by Dahl (1956) ; $Is = [2c/(a+b)] \times 100$, where Is is a similarity index, a is the sum of the cover classes for all the species in one relevé, b is the sum of the cover classes for all the species in other relevé, and c is the sum of smaller cover classes of common species to the two relevés. Cover class + was treated as 0.5.

Vascular plant nomenclature follows Porsild (1964) and, in a few cases, Hultén (1968). Bryophytes were identified by Dr. H. Kanda of the National Institute of Polar Research, Tokyo, Japan, and lichens by the author.

Results and discussion

Air and soil sub-surface temperatures

Figure 2 illustrates the diurnal fluctuation of air and soil sub-surface temperatures as recorded by the data loggers from July 25 th to August 14 th, 1991. During that period, these temperatures did not drop below 0℃. The maximum air temperature was 9.8℃ and minimum

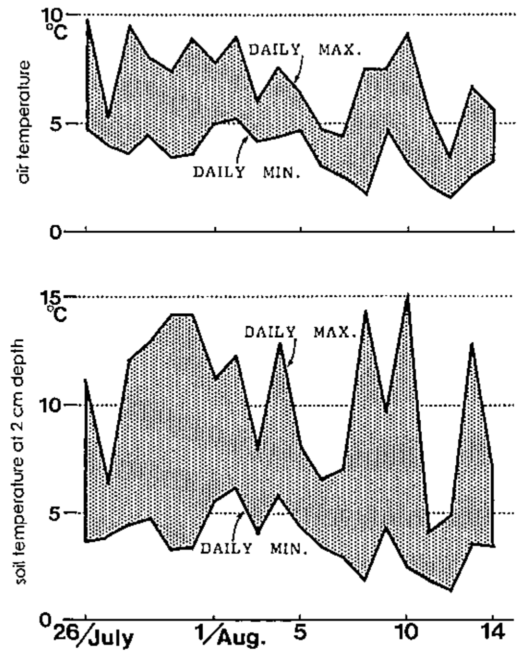

Fig. 2. Amplitudes of air and soil subsurface temperatures of the study area. The measurements were made for consecutive 20 days from July 26 th to August 14 th, 1991.

Table 1. Temperature characteristics of the study area. This table shows number of hours above certain base line temperatures and percentages to the total hours recorded (480 hours) for both air and soil subsurface temperatures.

base line	air temperature hours	air temperature %	soil subsurface temperature hours	soil subsurface temperature %
temperatures				
> 5℃	245	51.0	295	61.5
> 8℃	26	5.4	113	23.5
>10℃	0	0	57	11.8

1.4℃ ; the maximum soil subsurface temperature 15.1℃ and minimum 1.5℃. Diurnal air temperature ranges averaged 3.5℃ (maximum 6.3 ℃) and that of the soil sub-surface temperature 7.7℃(maximum 14.8℃). Table 1 shows the number of hours of air and soil sub-surface temperatures above 5℃, 8℃ and 10℃ during the consecutive 20 days of monitoring. Both air and soil sub-surface temperatures tended to descend from the beginning to the end of the measurement period. In August, the climate had already started to cool down.

Plant community types

A total of 57 relevés were established to represent various plant communities. Throughout the relevés, the most common species were *Salix arctica* (occurring in 45 relevés), followed by *Dryas integrifolia* and *Saxifraga oppositifolia* (in 29 relevés). *Poa abbreviata* and *Stellaria longipes* (in 22 relevés), and *Alopecurus alpinus* (in 18 relevés).

Similarity indices among the 57 relevés were calculated upon which basis a dendrogram was constructed (Fig. 3). It showed six relevé clusters segregated at approximately 60% of similarity. Each cluster consisted of relevés of a similar floristic composition and was, therefore, considered a separate plant community type. Then six plant community types were recognized as: 1) *Saxifraga oppositifolia* type, 2) *Saxifraga tricuspidata* type, 3) *Dryas integrifolia-Salix arctica* type, 4) *Cassiope tetragona* type, 5) *Alopecurus alpinus* type, and 6) *Carex stans* type. For each cluster, constancy classes were calculated. These types corresponded to plant associations in the sense of Braun-Blanquet (1964). A condensed synoptic vegetation table was provided (Table 2), which included only species having constancy class greater than Ⅲ in any of the six plant community types. Brief descriptions of these types are as follows.

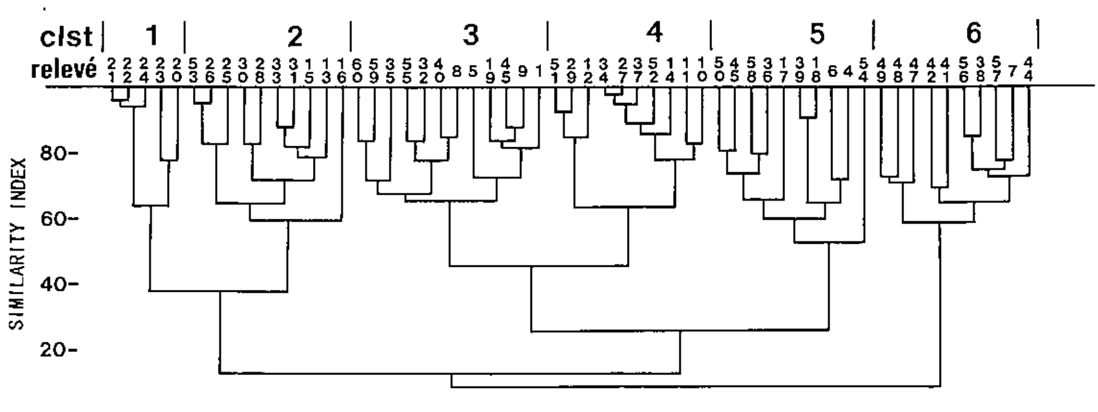

Fig. 3. A dendrogram based on vegetational similarities of the 57 relevés. It shows six clusters of releves, each of which represents a plant community type.

Table 2. Synoptic table of species structure and some environmental characteristics of six plant community types

type No.	1	2	3	4	5	6
plant community type*	So	St	DS	Ct	A	Cs
number of relevés	5	10	12	10	10	10
Species	average species significance / constancy class					
Saxifraga oppositifolia	5.20/V	4.47/V	2.05/III	2.19/IV	0.22/I	.
Papaver lapponicum	1.58/V	0.95/III	0.22/I	0.77/II	.	.
Saxifraga caespitosa	2.26/III	0.63/II	.	.	.	.
Draba groenlandica	1.26/IV	1.26/IV	0.45/II	0.32/I	.	.
Poa abbreviata	1.26/IV	2.00/V	1.34/III	0.22/I	0.32/I	.
Saxifraga tricuspidata	.	5.57/V	0.45/I	0.22/I	.	.
Minuartia rubella	0.63/I	1.26/IV	.	.	.	.
Carex nardina	.	2.85/III	.	.	.	.
Dryas integrifolia	.	2.12/III	4.80/V	4.00/V	0.55/I	0.32/I
Salix arctica	.	0.45/II	5.90/V	4.42/V	5.00/V	2.83/V
Cassiope tetragona	.	.	1.26/II	6.60/V	.	.
Carex misandra	.	0.45/I	0.45/II	2.73/IV	.	.
Alopecurus alpinus	.	0.22/I	1.10/II	.	6.04/V	0.32/I
Eriophorum scheuchzeri	.	.	.	.	2.57/III	1.41/II
Polygonum viviparum	.	.	0.22/I	.	1.64/III	1.61/II
Stellarea longipes	.	0.95/III	0.63/II	0.22/I	1.22/III	0.95/III
Juncus biglumis	.	.	.	0.22/I	2.53/IV	1.79/IV
Carex aquatilis ssp. *stans*	.	.	.	.	1.34/III	6.86/V
Saxifraga hirculus	.	.	.	.	0.45/I	3.39/V
Saxifraga cernua	0.32/I	.	.	0.22/I	0.32/I	1.73/V
Eriophorum triste	.	.	.	.	.	2.76/IV
Melandrium apetalum	.	.	.	.	0.32/I	1.34/III
Dupontia fisheri	.	.	.	.	0.22/I	1.22/III
# of vascular species/relevé	5.2	8.6	5.8	6.6	8.2	9.6
total vegetative cover (%)	22	60	80	99	95	100
total cover of cryptogams (%)	16	26	32	40	52	61
soil moisture regime	xeric	xeric	mesic	mesic	hygric	hygric
average soil pH	8.1	7.4	7.6	6.3	7.6	6.7

* So: *Soxifraga oppositifolia* type; St: *Saxifraga tricuspidata* type; Ds: *Dryas integrifolia-Salix arctica* type; Ct: *Cassiope tetragona* type; A: *Alopecurus alpinus* type; Cs: *Carex aquatilis* ssp. *stans* type.

1. *Saxifraga oppositifolia* Community type (Fig. 4-A)

This plant community occurs generally in well-drained xeric habitats of glacial deposits, on mass wasting and scree slopes. It is one of the most extensive types in the Sverdrup Pass and in the High Arctic (Bliss and Svoboda 1984). Ground surface is largely paved with gravels and shattered rocks. Soils are mostly weakly developed Regosolic Static Cryosols but in less well drained soils, Regosolic Turbic Cryosols develop. Total plant cover averaged 22%, which was the lowest of the six community types. *Saxifraga oppositifolia* exhibited a high constancy and dominance in species cover. *Papaver lapponicum* also showed a high constancy, *Saxifraga caespitosa* showed a relatively high dominance. Other major vascular species included *Draba groenlandica* and *Poa abbreviata*. Average number of species per relevé was 5.2, which was also lowest of the six community types. Cover of the cryptogamic community was very low. Lichens such as *Thamnolia subuliformis, Alectoria ochroleuca, Cetraria islandica, C. nivalis* and *Cornicularia divergens* were common and dominated over bryophytes.

This community type is comparable to the Moss-Herb type from Devon Island (Muc and Bliss 1977), the *Saxifraga-Papaver* community type from Somerset and Prince of Wales Islands (Woo and Zoltai 1977), the purple saxifrage

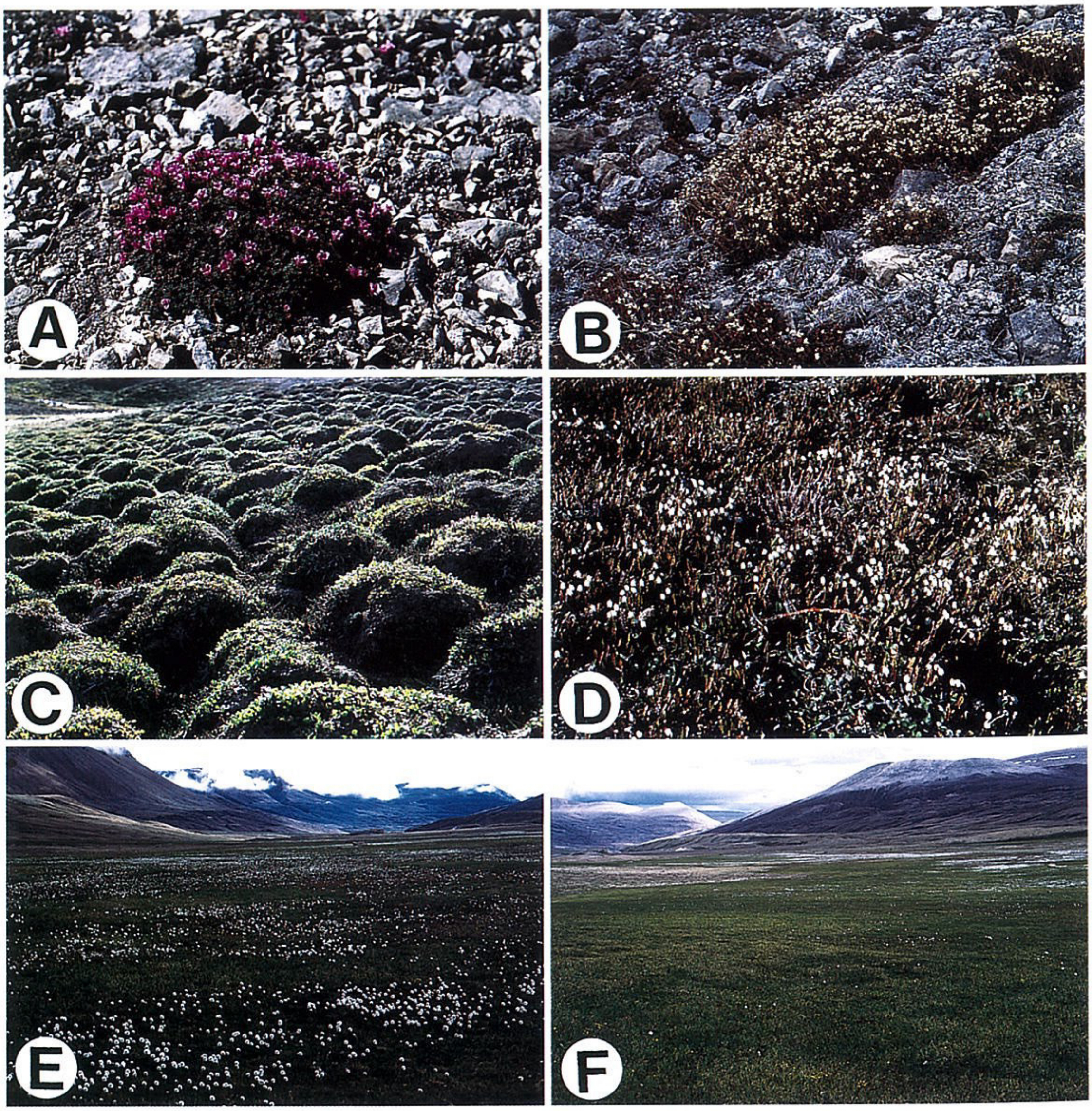

Fig. 4. General view of the six plant community types. A : *Saxifraga oppositifolia* type ; B : *S. tricuspidata* type ; C : *Salix arctica-Dryas integrifolia* type ; D : *Cassiope tetragona* type ; E : *Alopecurus alpinus* type ; F : *Carex aquatilis* ssp. *stans* type.

plains type from Boothia Peninsula (Thompson 1980), the ridge community from Bathurst Island (Sheard and Geale 1983 a), the *Saxifraga caespitosa* type from Cornwallis island (Kojima 1991), and the *Saxifraga oppositifolia-Luzula* type from Alexandra Fiord, Ellesmere Island (Batten and Svoboda 1994). The present type, however, appears to occur on drier and more barren-like habitats than those described from elsewhere.

2. *Saxifraga tricuspidata* Community type (Fig. 4-B)

This community type occurs in well-drained xeric habitats of shallow lithic soils. The dominant *Saxifraga tricuspidata* frequently grows among rocks devoid of fine soil material. This type has best developed on granitic substrates. Total plant cover was comparatively low as it was 60% on average. *S. tricuspidata* showed characteristically high dominance and constancy. *S. oppositifolia* was always present as a codominant. Other major vascular plants included *Poa abbreviata, Draba groenlandica, Minuartia rubella, Papaver lapponicum, Dryas integrifolia, Stellaria longipes*, and *Carex nardina*. Despite the xeric habitats, this type included the second highest number of vascular species per relevé, i. e., 8.6 species on average. Coverage of lichens including *Alectoria ochroleuca, Cetraria cuculata, C. nivalis*, and *Cornicularia divergens* was greater than that of bryophytes. Major bryophytes included *Bryum argenteum, Distichium capillaceum, Hypnum cupressiforme*, and *H. revolutum*.

This type is not common in the eastern Canadian High Arctic possibly because of the predominance of calcareous soils (Barrett 1972; Walker and Peters 1977; Woo and Zoltai 1977) as *Saxifraga tricuspidata* grows better in acidic soils. None of the previous studies has described a community type dominated and characterized by this species.

3. *Dryas integrifolia-Salix arctica* Community type (Fig. 4-C)

This community type has developed on gentle slopes or a leveled topography in medium to fine textured soils. It is the most common plant community in the study area occurring extensively in mesic habitats. Total plant cover was ca. 80% on average. *Salix arctica* showed a high dominance and constancy, followed by *Dryas integrifolia*. Other major vascular plants included *Poa abbreviata, Saxifraga oppositifolia, Cassiope tetragona*, and *Alopecurus alpinus*. The number of vascular species averaged 5.8 / relevé, which was the second lowest. Cryptogamic cover was relatively high with bryophytes prevailing over lichens. Major bryophytes included *Campylium arcticum, Distichium capillaceum, Orthothecium chryseum*, and *Tortula ruralis*. One of the characteristic features of this type was its frequent association with well developed earth hummocky terrain in the study area (Kojima, 1994). Earth hummocks were covered mainly by *Salix arctica* mixed with *Dryas integrifolia*. In delayed snowmelt areas *Cassiope tetragona* was often present.

This community type is somewhat comparable to Pedicularo - Dryadetum integrifoliae and Pogonato - Luzulo - Salicetum arcticae of Barrett (1972), the cushion plant-moss community of Muc and Bliss (1977), the *Salix-Dryas* community of Woo and Zoltai (1977), the *Salix arctica* dominant community described from Sverdrup Pass by Bergeron and Svoboda (1989), the lichen -cushion plant-dwarf shrub community from Alexandra Fiord (Muc et al. 1989), and the *Dryas integrifolia* type described by Kojima (1991).

4. *Cassiope tetragona* Community type (Fig. 4-D)

This community has developed in mesic habitats on gentle slopes with relatively deep soils. It is better developed on north-facing slopes and slope bases where presumably snow stays longer in spring. In the study area, distribution of this type seems to be limited and associated with the areas where granitic substrates predominate. But in the mid-Arctic, this type of communities is reportedly more common (Woo and Zoltai, 1977). Total plant cover was 99% on average. *Cassiope tetragona* showed very high dominance and constancy. *Salix arctica* and *Dryas integrifolia* also exhibited high constancy. Other major species included *Saxifraga oppositifolia, Carex misandra*, and *Luzula confusa*. There were 6.6 species per relevé on average. The cryptogamic community was well developed and it was dominated by *Aulacomnium acuminatum, Campylium arcticum, Ditrichum flexicaule*, and *Orthothecium chryseum*.

This community type is comparable with Sphaerophoro-Rhacomitrio-Cassiopetum tetragonae of Barrett (1972), the dwarf shrub heath-moss community of Muc and Bliss (1977), the *Cassiope-Cetraria* community of Woo and Zoltai (1977), the *Dryas integrifolia* dominated community of Bergeron and Svoboda (1989), the dwarf -cushion plant type community of Muc et al. (1989), and the *Salix-Cassiope* type of community of Batten and Svoboda (1994).

5. *Alopecurus alpinus* Community type (Fig. 4-E)

This community has developed in wet habitats of slope bases, valley bottoms, and along riverbeds, where water collects. Water table is present within 30 to 50 cm below the ground surface. Soils are generally deep and fine textured and are frequently of clayey texture. Soils are mostly Gleysolic Static Cryosols. Salt crusts are occasionally noticeable on dried-up soil surface. Total plant cover was as high as 95% on average. *Alopecurus alpinus* showed high dominance and constancy, followed by *Salix arctica*. *Juncus biglumis* was frequently present though its coverage was not high. Other major vascular species included *Eriophorum scheuchzeri*, *Polygonum viviparum*, *Stellaria longipes*, and *Carex aquatilis* ssp. *stans*. All vascular plants averaged 8.2 per relevé. The cryptogamic community was well developed and almost exclusively consisted of bryophytes such as *Bryum amblyodon*, *Campyliadelphus elodes*, *C. stellatus*, *Distichium capillaceum*, *Ditrichum flexicaule*, *Drepanocladus aduncus*, *D. vernicosus*, and *Orthothecium chryseum*.

This community type is comparable to the arctic sedge meadow of Woo and Zoltai (1977), the moss-graminoid meadow of Bliss and Svoboda (1984), the *Salix arctica*-grass community of Bergeron and Svoboda (1989), the *Dupontia-Alopecurus* type of Kojima (1991), and the *Dryas-Carex* type of Batten and Svoboda (1994).though *Dryas integrifolia* is not so prominent in the present type.

6. *Carex aquatilis* ssp. *stans* Community type (Fig. 4-F)

This distinct community is occurring in poorly drained hydric habitats with saturated soils. It is widely distributed in the High Arctic in wet valley bottoms and along seepage beds, on margins of lakes and stream edges. Soils are generally fine textured with peaty organic build-ups on the top of the solum. Soils are mostly Gleysolic Static Cryosols. Permafrost table is detectable at the depth 30-40 cm below the ground surface. Total plant cover was high (almost 100%). *Carex aquatilis* ssp. *stans* dominated with high constancy. Other major vascular species included *Saxifraga hirculus*, *S. cernua*, *Polygonum viviparum*, *Salix arctica*, *Eriophorum triste*, *Juncus biglumis*, *Stellaria longipes*, and *Melandrium apetalum*. Vascular species diversity was highest here with 9.6 species per relevé on average. The cryptogamic community was very well developed consisting exclusively of bryophytes such as *Calliergon giganteum*, *Campyliadelphus stellatus*, *Drepanocladus aduncus*, *D. lycopodioides*, *D. vernicosus*, *Myurella julacea*, *Orthothecium chryseum*, and *Philonotis fontana*.

This community type corresponded to Carisetum stanis of Barrett (1972), the wet sedge-moss meadow of Muc and Bliss (1977), the *Carex-Drepanocladus* community of Woo and Zoltai (1977), the sedge madow of Thompson (1980) and of Sheard and Geale (1983 a), the *Carex aquatilis-Eriophorum triste* meadow of Bergeron and Svoboda (1989), the *Carex stans* type of Kojima (1991), and the *Carex* meadow of Batten and Svoboda (1994).

Soil Profile Characteristics

Soil profiles differed considerably from relevé to relevé. Some were extremely shallow with a lithic contact at 5 to 10 cm depth, while others were much deeper. Some were very stony, others fine-textured. In general, horizon development was weak due to intense physical weathering, high cryoturbation, low amount of precipitation, and low biological activities. Accumulation of organic matter was generally small. However, in the *Carex aquatilis* ssp. *stans* Community type, exceptionally thick organic layer was noticeable. Such a soil was regarded as a bog soil by Cruickshank (1971). In some soils, involution and churning were recognized as indicated by marble-like patterns. Figure 5 shows diagrammatic sketches of some representative soil profiles of the community types.

In general, soils were alkaline as majority of samples were of pH greater than 7.0 except for those from the *Cassiope tetragona* Community type which showed slightly acidic reaction. The analysis of variance (one-way ANOVA) showed a highly significant difference among the community types ($n=20$, $df=5,14$, $F=24.89$, $p<0.0001$; see Table 3). The Scheffe's F test also indicated that the *Cassiope tetragona* Community type and *Carex aquatilis* ssp. *stans* Community type, both of which exhibited low pH values, significantly differed from others. Based on the soil pH, the six community types may be divided into two groups: 1) *Saxifraga oppositifolia*, *S. tricuspidata*, *Dryas-Salix*, and *Alopecurus alpinus* Community types, and 2) *Cassiope tetragona*, and *Carex aquatilis* ssp. *stans* Community types.

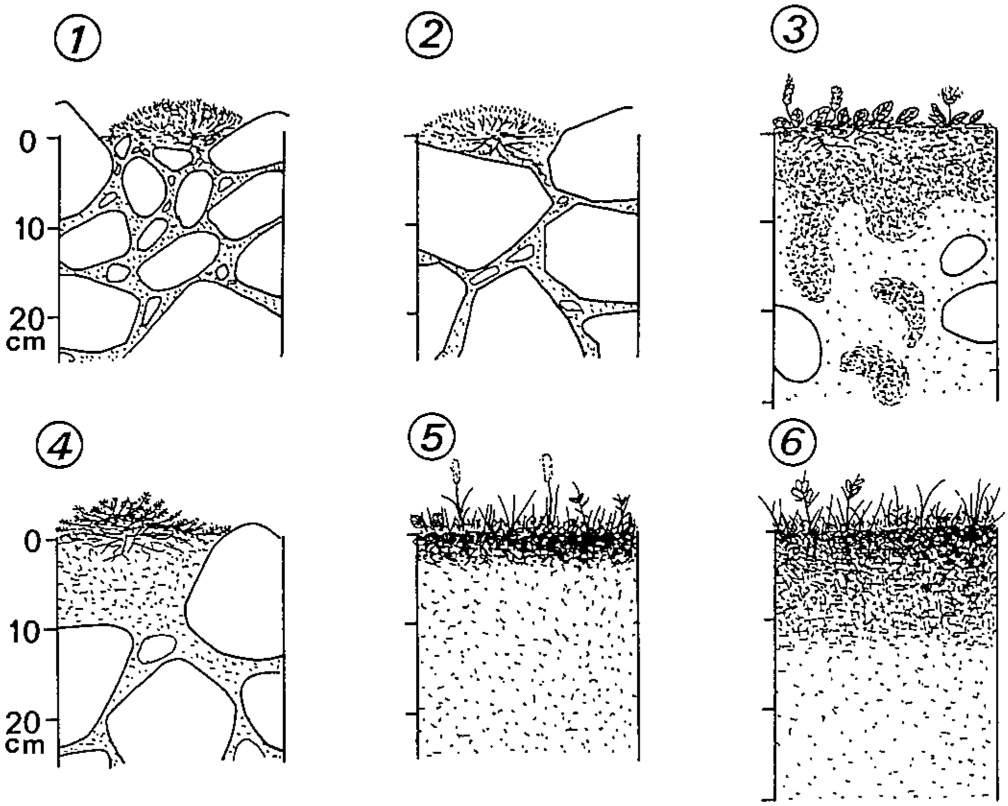

Fig. 5. Schematic sketches of soil profiles in the six plant community types. The circled numbers correspond to those of the plant community type numbers described in the text.

Table 3. Soil pH values of selected relevés and comparison of averages among the six plant community types by Scheffe's test. Letters after the averages indicate significant differences at $p < 0.05$ level.

Plant community type	relevé No.	pH	average of pH
Saxifraga oppositifolia type	22	8.20	8.07 a
	23	7.95	
	24	8.07	
Saxifraga tricuspidata type	13	7.34	7.59 a
	15	7.74	
	31	7.65	
Dryas-Salix type	19	7.68	7.61 a
	31	7.34	
	35	7.78	
	40	7.55	
	59	7.70	
Cassiope tetragona type	11	6.59	6.24 b
	14	6.15	
	27	5.99	
Alopecurus type	17	7.79	7.65 a
	18	7.63	
	36	7.53	
Carex type	41	7.21	6.73 b
	42	6.42	
	44	6.56	

The *Cassiope tetragona* Community type develops generally on gentle north-facing slopes or at slope bases where snow tends to accumulate. It is common especially in granitic soils. In the *Carex aquatilis* ssp. *stans* Community type, peat accumulation is characteristic, which would reduce the soil pH.

The soil surface temperatures greatly varied depending on site aspect, degree of wetness, time of the day, weather conditions, and substrate characteristics. In the xeric sites such as those of the *Saxifraga oppositifolia* and *S. tricuspidata* Community types, the soil surface temperatures showed the high-

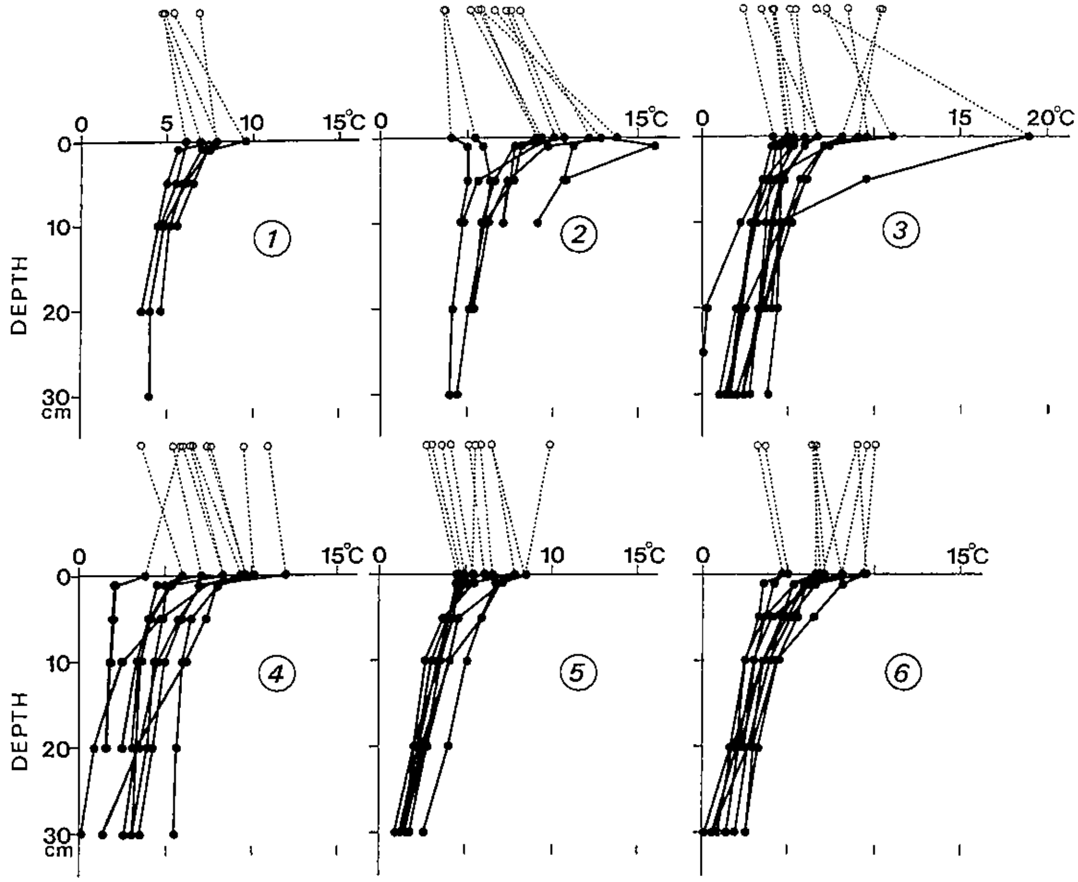

Fig. 6. Soil temperatures of the plant community types at different depths. The circled numbers represent the plant community types as described in the text. Solid line represents temperature changes. Open circles at the top indicate air temperature at the time of the soil temperature measurements, and dotted line links the air and soil temperatures.

est temperature amplitudes. In contrast, under saturated conditions as in the *Alopecurus alpinus* and *Carex aquatilis* ssp. *stans* community types, temperature variation was small. Figure 6 illustrates soil temperatures at different depths for the six plant community types. In general, soil surface temperature greatly varied from relevé to relevé. Temperature variation was particularly great in the top 10 cm. Below that depth, however, temperature appeared to converge. Soil temperatures of the *Saxifraga oppositifolia* type and *S. tricuspidata* type were particularly variable. This was presumably due to terrain surface conditions, i.e., the habitat was well drained and paved with coarse gravels and stones. Temperature variation was relatively small for the *Alopecurus* type and *Carex* type, where soils were always saturated with water. If we assume 5℃ as a threshold temperature for biological activity, the thickness of biologically active rhizosphere in this study area will be approximately 5 to 10 cm or so from the ground surface.

Plant communities and edaphic environment relationships

In the High Arctic, soil moisture is an important factor determining plant community development (Muc 1977; Webber 1978; Thompson 1980; Sheard and Geale 1983 b; Miller and Alpert 1984; Bliss et al. 1984; Bergeron and Svoboda 1989; Kojima 1991; Muc et al. 1994). Because of the small amount of summer precipitation and generally low water holding capacity

Table 4. Correlation coefficients among A (number of vascular species / relevé), B (total plant cover of relevé), C (soil moiusture status) and D (soil pH). (n=20)

	B	C	D (soil PH)
A : number of vascular species / relevé	0.542	0.518	−0.421
B : total plant cover of relevé	·	0.828*	−0.743**
C : soil moisture status	·	·	−0.406

*p<0.05 ; **p<0.10.

of soils, plant community development is very much regulated by water availability. In this respect, plant communities differ considerably according to their topographical position ; sloping habitats are well drained while in flat uplands or lowlands ample water is usually available to plants since the permafrost table restricts drainage.

Soil base status is another important factor affecting vegetation development (Woo and Zoltai 1977). Soil pH is a good indicator of soil base status (Daubenmire 1965). Soils in this study area are generally higher in base status as indicated by higher soil pH than those in Alexandra Fiord (Muc et al. 1994). This is probably due to extensive occurrences of dolostone and limestone substrates and less amount of precipitation, especially in summer season, than in the Alexandra Fiord. In such soils, calciphilous plants are more successful in establishment. Plant communities occurring in these habitats include a number of calcicoles, for example, *Braya purpurascens, Lesquerella arctica, Saxifraga caespitosa*, and *S. oppsitifolia*. Highly calcareous conditions, however, are not well tolerated by most species, hence, more diverse and lusher vegetation develops on granitic substrates. Woo and Zoltai (1977) reported richer vegetation in siliceous sandstone outcrops, surrounded by extensive limestone. Vegetated "islets" in the "sea" of barren landscape developed there. Soil moisture and base status may have played decisive role in differentiating plant communities in the Sverdrup Pass area as well.

Using the data in Table 3, correlation coefficients were calculated between the average number of vascular species per relevé (A), average total plant cover per relevé (B), soil moisture regime (C), and soil pH (D) for the six plant community types (Table 4). Moisture regime was quantified as xeric=1, mesic=2, and hydric=3. Total plant cover exhibited a significant positive correlation with soil moisture regime and negative one with the soil pH. Other correlation coefficients were not significant at p<0.10 level. This indicated that, besides the frigid conditions, moisture availability was another crucial factor for lush development of plant communities because of generally low amount of precipitation and high base status owing to extensive calcareous geology which provided excess of basic cations unless they were leached out by water.

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References

Barrett, P.E. 1972. Phytogeocoenoses of a coastal lowland ecosystems, Devon Island, N.W.T. xiv +292 pp. Ph.D. thesis, Univ. British Columbia, Vancouver.

Batten, D.S. and Svoboda, J.S. 1994. Plant communities on the upland in the vicinity of the Alexandra Fiord Lowland. *In* Svoboda, J.S. and Freedman. B. (ed.). Ecology of polar oasis. Alexandra Fiord, Ellesmere Island, Canada, pp.97–110. Captus Press, North York.

Bergeron, J-F. and Svoboda, J.S. 1989. Plant communities of Sverdrup Pass, Ellesmere Island, N.W.T. Musk-ox **37** : 76–85.

Bliss, L.C. 1977. Introduction. *In* Bliss, L.C. (ed.). Truelove Lowland, Devon Island, Canada : a High Arctic ecosystems, pp.1–11. Univ. Alberta Press, Edmonton.

Bliss, L.C. and Svoboda, J.S. 1984. Plant communities and plant productions in the western Queen Elizabeth Islands, N.W.T. Holarctic Ecology **7** : 325–344.

Bliss, L.C., Svoboda, J.S. and Bliss, D.I. 1984. Polar deserts, their plant cover and plant production in the Canadian High Arctic. Holarctic Ecology **7** : 305–324.

Braun-Blanquet, J. 1964. Plant sociology. (English translation of Pflanzensoziologie by Fuller, G.D. and Conrad, H.S.). 439 pp. Hafner, New York.

Canada Soil Survey Committee. 1978. The Canadian system of soil classification. 194 pp. Research Branch, Can, Dept. Agr. Publ. 1646. Printing and Publishing Supply and Services Canada, Hull.

Chapin Ⅲ, F.S., Jeferreries, R.L., Reynolds, J.F., Shaver, G.R. and Svoboda, J.S. 1992. Arctic ecosystems in a changing climate - an ecophysiological perspective. 469 pp. Academic Press, San Diego.

Charlier, R.H. 1969. The geographical distribution of polar desert soils in the northern hemisphere. Geol. Soc. Amer. Bull. **80** : 1985–1996.

Cruickshank, J.G. 1971. Soils and terrain units around Resolute, Cornwallis Island. Arctic **24** : 195–209.

Dahl, E. 1956. Rondane : mountain vegetation in south Norway and its relation to the environment. 374 pp. Norsk. Vidensk. Akadem, Oslo.

Daubenmire, R.F. 1965. Plants and Environment. 422 pp. John Wiley and Sons, New York.

Freedman, B., Svoboda, J.S., Labine, C., Muc, M., Henry, G.H.R., Nams, M., Stewart, J. and Woodley, E. 1983. Physical and ecological characteristics of Alexandra Fiord - a high arctic oasis on Ellesmere Island, Canada. *In* Proc. 4 th Int. Conf. Permafrost, pp.301–304. National Academy Press, Washington, D.C.

Griggs, R.F. 1934. The problem of arctic vegetation. J. Wash. Acad Sci. **24** : 153–175.

Henry, G.H.R. (ed.) 1997. The international tundra experiment (ITEX) : short-term responses of tundra plants to experimental warming. Global Change Biology **3** (Suppl. 1) : 1–164 .

Hultén, E. 1968. Flora of Alaska and neighboring territories. 1008 pp. Stanford Univ. Press, Stanford.

Kojima, S. 1991. Vegetation and environment of the Canadian High Arctic with special reference to Cornwallis Island. Proc. NIPR Symp. Polar Biology **4** : 135–154.

Kojima, S. 1994. Relationships of vegetation, earth hummocks and topography in the high arctic environment of Canada. Proc. NIPR Symp. Polar Biology **7** : 256–289.

Köppen, W. 1936. Das geographische System der Klimat. *In* Köppen, W. and Geiger, R. (ed.). Handbuch der Klimatologie. Band I, Teil C. 46 pp. Gebruder Borntraeger, Berlin.

Krajina, V.J. 1933. Die Pflanzengesellschaften des Mlynica-Tales in den Vysoke Tatry (Hohe Tatra). Bot Cbl. Beih., Abt. II. **50** : 1–224.

Labine, C. 1994. Meteorology and climatology of the Alexandra Fiord Lowland. *In* Svoboda, J. S. and Freedman. B. (ed.). Ecology of polar oasis. Alexandra Fiord, Ellesmere Island, Canada, pp.23–39. Captus Press, North York.

Levesque, E., Henry, G.H.R. and Svoboda, J.S. 1997. Phenological and growth responses of *Papaver radicatum* along altitudinal gradients in the Canadian High Arctic. Global Change Biology **3** (Suppl. 1) : 125–145.

Maxwell, J.B. 1981. Climate regions of the Canadian arctic islands. Arctic **34** : 225–240.

Miller, N.G. and Alpert, P. 1984. Plant associaitons and edaphic features of a High Arctic mesotopographic setting. Arct. Alp. Res. **16** : 11–24.

Muc, M. 1977. Ecology and primary production of sedge-moss meadow communities, Truelove Lowland. *In* Bliss, L.C. (ed.). Truelove Lowland, Devon Island, Canada : a High Arctic ecosystems, pp.157–184. Univ. Alberta Press, Edmonton.

Muc, M. and Bliss, L.C. 1977. Plant communities in Truelove Lowland. *In* Bliss, L.C. (ed.).

Truelove Lowland, Devon Island, Canada: a High Arctic ecosystems, pp.143–154. Univ. Alberta Press, edmonton.

Muc, M., Freedman, B. and Svoboda, J.S. 1989. Vascular plant communities of a polar oasis at Alexandra Fiord (79 N), Ellesmere Island, Canada. Can. J. Bot. **67**: 1126–1136.

Muc. M., Svoboda, J. and Freedman, B. 1994. Soils of an extensively vegetated polar desert oasis, Alexandra Fiord, Ellesmere Island. *In* Svoboda, J.S. and Freedman. B. (ed.). Ecology of polar oasis. Alexandra Fiord, Ellesmere Island, Canada, pp.41–50. Captus Press, North York.

Porsild, A.E. 1964. Illustrated flora of the Canadian arctic archipelago. Nat. Mus. Can. Bull. 146. 218 pp. Nat. Museum, Ottawa.

Ryden, B.E. 1977. Hydrology of Truelove Lowland. *In* Bliss, L.C. (ed.). Truelove Lowland, Devon Island, Canada: a High Arctic ecosystems, pp.281–300. Univ. Alberta Press, Edmonton.

Savile, D.B.O. 1960. Limitations of the competitive exclusion principles. Science **132**: 1761.

Sheard, J.W. and Geale, D.W. 1983 a. Vegetation studies at Polar Bear Pass, Bathurst Island, N.W.T. I. Classification of plant communities. Can. J. Bot. **61**: 1618–1636.

Sheard, J.W. and Geale, D.W. 1983 b. Vegetation studies at Polar Bear Pass, Bathurst Island, N.W.T. II. Vegetation-environment relationships. Can. J. Bot. **61**: 1637–1646.

Sϕrensen, T. 1948. A method of establishing groups of equal amplitude in plant sociology based on similarity of species content. Dan. Vidensk. Selsk. Biol. Skr. **5**: 1–34.

Svoboda, J.S. 1990. Origin and development of polar oasis. V. INTECOL Symp. Abstracts (S 1-4-08-04): 86.

Svoboda, J.S. and Freedman, B. (ed.). 1994. Ecology of polar oasis. Alexandra Fiord, Ellesmere Island, Canada. 268 pp. Captus Press, North York.

Tedrow, J.C.F. 1966. Polar desert soils. Soil Sci. Soc. Amer. Proc. **30**: 381–387.

Tedrow, J.C.F. 1977. Soils of the polar landscapes. 638 pp. Rutgers Univ. Press, New-Brunswick.

Thompson, D.C. 1980. A classification of the vegetation of Boothia Peninsula and the northern district of Keewatin, N.W.T. Arctic **33**: 73–99.

Thorsteinsson, R. and Tozer, E.T. 1970. Geology of the arctic archipelago. *In* Douglas, R.J.W. (ed.). Geology and economic minerals of Canada. Geol. Survey Can. Econ. Geol. Rep. No.1, pp.547–590. Geological Survey of Canada, Ottawa.

Walker, B.D. and Peters, T.W. 1977. Soils of Truelove Lowland. *In* Bliss, L.C. (ed.). Truelove Lowland, Devon Island, Canada: a High Arctic ecosystems, pp.31–62. Univ. Alberta Press, Edmonton.

Walker, M.A., Daniels, F.J.A. and Van der Maarel, E. 1994. Circumpolar arctic vegetation: introduction and perspectives. J. Veg. Sci. **5**: 758–764.

Webber, P. J. 1978. Spatial and temporal variation of the vegetation and its production, Barrow, Alaska. *In* Tieszen, L.L. (ed.). Vegetation and production ecology of an Alaskan arctic tundra, pp.37–112. Springer-Verlag, New York.

Woo, V. and Zoltai, S.C. 1977. Reconnaissance of the soils and vegetation of Somerset and Prince of Wales Islands, N.W.T. Information Report NOR-X-186. pp.37–112. Can. For. Serv., Northern Forest Resrearch Centre, Edmonton.

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小島　覚：カナダ北極圏エルズミア島における植物群落型の分化と土壌条件

カナダ北西準州，エルズミア島スヴェルドラップ峠地域における植物群落分化の様相を観察記録し，分化を成立させている環境要因を特に土壌特性との関連で考察した。調査地は，北緯79度08分，西経80度30分に位置し，全域が極地砂漠と呼ばれる極端に植被率の低い地域に包含される。気温は，調査を行った7月26日から8月14日の間において，10℃を越えることがなかった。本調査地において認められたさまざまな植物群落に対し，5m × 5mの方形区（relevé）を57個所において設定し，それらを植生類似度及び群落組成から類型化したところ，1. *Saxifraga oppositifolia* 型，2. *S. tricuspidata* 型，3. *Dryas integrifolia-Salix arctica* 型，4. *Cassiope tetragona* 型，5. *Alopecurus alpinus* 型，

6. *Carex aquatilis* ssp. *stans* 型の6植物群落型が識別された。これらの群落型は，第一義的には土壌の湿潤度により分化成立するものであった。すなわち，群落型1および2は乾性地に，2および3は適潤地に，5及び6は湿性地に発達していた。土壌のpHは，群落型1において最も高く（平均8.07），また4において最も低く（平均6.24），他は両者の中間の値を示した。

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