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VEGETATION AND ENVIRONMENT OF THE CANADIAN HIGH ARCTIC WITH SPECIAL REFERENCE TO CORNWALLIS ISLAND

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Abstract: Vegetation of Cornwallis Island, Canada, was studied. A total of fifty-one sample plots were established to represent the vegetation of the high arctic. The plots were assembled and classified according to the phytosociological procedures. Seven vegetation types each of which may be comparable to plant association (*sensu* KRAJINA) were distinguished, namely, 1. *Saxifraga caespitosa-Poa arctica* type, 2. *Saxifraga oppositifolia-Draba bellii* type, 3. *Saxifraga oppositifolia-Festuca baffinensis* type, 4. *Saxifraga oppositifolia-Dryas integrifolia* type, 5. *Saxifraga oppositifolia-Salix arctica* type, 6. *Dupontia fisheri-Alopecurus alpinus* type, and 7. *Carex stans* type. Edaphic conditions in terms of soil moisture regime and coarseness of substrates were assessed and correlated with the vegetation types. Moisture availability seemed to have been an important factor to regulate the vegetation development. When habitat was moist enough, vegetation obviously exhibited a high plant coverage and species diversity. Nutrient supply seemed to be also another important factor as lush growth of vegetation was recognized in nutritionally enriched sites. It was concluded that, even under a frigid climate of the arctic environment, the desolate landscape of polar desert was in fact substantiated by an insufficient supply of moisture and nutrients.

1. Introduction

For the past few decades, arctic biome has been a subject to intensive social, economical, and scientific concerns of the northern countries in relation to exploitation and conservation of natural resources including biological and non-biological resources. In recent years, it has become also a well-focused region from the global environmental point of view such as possible climatic warming and its potential effects on the physical as well as socio-economic environment of the north.

In the Canadian arctic, a great number of floristic and vegetation studies have been conducted since middle of this century. Among them notably are: POLUNIN (1948), CODY (1951), SCHOFIELD and CODY (1955), PORSILD (1955, 1964), SAVILE (1959, 1960, 1961), BARRETT (1972), BABB and BLISS (1974a, b), WEIN and RENCZ (1976), BELL and BLISS (1977, 1978, 1980), WOO and ZOLTAI (1977), ZOLTAI (1978), ZOLTAI and JOHNSON (1978), ADDISON and BLISS (1980), ZOLTAI *et al.* (1980, 1981), PETERSON *et al.* (1981), SOHLBERG and BLISS (1984), BLISS and SVOBODA (1984), and BLISS *et al.* (1984). A comprehensive treatise of high arctic ecosystems in Devon Island by biologists of various specializations during the IBP activities was compiled by BLISS (1977).

Those studies have accumulated a great amount of information on the floristic and vegetational characteristics of the northern ecosystems. As a result, state of knowledge on the ecology of the Canadian arctic has become much improved. However, local site specific information on vegetation differentiation in relation to environment is not necessarily sufficiently known mainly because of the vastness and poor accessibility of the area.

Objectives of the present study are to classify and describe the vegetation developing in Cornwallis Island, Northwest Territories, Canada, and to provide interpretation as to the differentiation of the vegetation in relation to the environment, especially edaphic conditions.

2. Definition and Division of Arctic Biome

In this article, arctic is defined as an area located in northern high latitudes north of tree line. A tree line is an imaginary line connecting points of the northernmost outliers of tree species which normally grow in a tree form with a height well over 5 m tall in favorable conditions. The tree line is, thus, comparable to the Nordenskjold line (NORDENSKJOLD and MECKING, 1928). Arctic is, therefore, an area characterized by an extensive development of tundra physiognomy.

There are several schemes proposed as to the geographical as well as ecological divisions of the arctic biome. Table 1 compares some of the major ones.

Table 1. Schemes of geographical division of the arctic biome.

<table>
<tr><th colspan="2">POLUNIN, N. (1951)</th><th colspan="2">ZOLTAI, S. C. (1977)</th><th colspan="3">BLISS, L. C. (1977)</th><th colspan="4">ALEKSANDROVA, V. D. (1971)</th></tr>
<tr><td rowspan="5">arctic</td><td rowspan="2">high-arctic</td><td rowspan="5">arctic</td><td rowspan="2">high-arctic</td><td rowspan="5">arctic</td><td rowspan="4">high arctic</td><td>polar desert</td><td rowspan="7">arctic</td><td rowspan="2" colspan="2">polar desert</td><td>northern</td></tr>
<tr><td>polar semi-desert</td><td>southern</td></tr>
<tr><td rowspan="2">mid-arctic</td><td rowspan="2">mid-arctic</td><td rowspan="2">complexes of sedge meadows and polar semi-desert</td><td rowspan="5">tundra</td><td rowspan="2">arctic tundra</td><td>northern</td></tr>
<tr><td>southern</td></tr>
<tr><td>low-arctic</td><td>low-arctic</td><td colspan="2">low arctic</td><td rowspan="3">subarctic tundra</td><td>northern</td></tr>
<tr><td colspan="2" rowspan="2"></td><td colspan="2" rowspan="2">subarctic</td><td colspan="3" rowspan="2">subarctic</td><td>middle</td></tr>
<tr><td>southern</td></tr>
</table>

POLUNIN (1951) demarcated the arctic from its southern counterpart, *i.e.* subarctic, by a line approximately 80 km north of continuous forest or by a tree line of microphanerophytic tree growth of 2–8 m height, or by the Nordenskjord line. He then divided the arctic into three sections, *i.e.* low-arctic, mid-arctic, and high-arctic, based mainly on a degree of vegetative cover and floristic characteristics. The low-arctic which was located in the southernmost latitudes in the biome was characterized by well-developed vegetation with a high degree of vegetative cover nearly 100% in most instances and a high diversity of vascular plants. Well-developed shrubby vegetation represented by *Salix* and shrubby *Betula*, both of which could attain nearly 5 m tall, was characteristic. "Heath" vegetation made up of *Vaccinium*, *Ledum* and *Empetrum* occurred commonly. Development of wetlands with a considerable amount of peat accumulation was extensive. The mid-arctic was situated between the low- and high-arctics. It was characterized by an extensive development of "heath" vegetation while tall shrub vegetation became extremely rare and confined only to south-facing well-drained habitats. Wetlands dominated by *Carex*, *Arctagrostis*, and *Eriophorum* were extensive. In general, vegetative cover in the mid-arctic was rather high. The high-arctic was located in the northernmost latitudes. Its species diversity of vascular plants was low. It was characterized by desolate and sparsely vegetated landscape. Vegetative cover was extremely low thus largely leaving devoid of vegetation. Fell-field occupied extensive areas reflecting more intensive physical weathering of the parent rocks than chemical weathering. Vegetation was best represented by sparse occurrences of *Saxifraga*, *Dryas*, *Papaver*, *Draba*, and *Poa*. Those plants usually grew in cushions, tufts, or rosette forms, exhibiting somewhat characteristic physiognomy. "Heath" was extremely rare and was strictly confined to snow-bed habitats. Wetlands became less common and developed in habitats along streams, flood plains, and snow-flushes.

Basically following the POLUNIN's concept, ZOLTAI (1977, 1978) divided the arctic biome of Canada into three sections, *i.e.* low arctic, mid arctic, and high arctic, primarily on the basis of degree of vegetative cover. He provided a map showing the division. BLISS (1977) recognized two basic zones for the Canadian arctic, *i.e.* high arctic and low arctic (Fig. 1), again based on the vegetation characteristics. He further subdivided the high arctic into three sections, *i.e.* polar desert, polar semi-desert, and complexes of sedge meadows and polar semi-desert, based on vegetative cover and physiognomy.

ALEKSANDROVA (1971) proposed a somewhat different scheme for the northern Eurasian continent to include the subarctic (*sensu* POLUNIN) into the arctic, thus proposing a quite broad concept of the arctic. According to the scheme, the arctic was physiognomically divided into two sections, *i.e.* tundra and polar desert. Tundra was the areas with more or less high vegetative cover but practically lacking trees. It was further divided into subarctic and arctic, each of which was further subdivided geographically into sub-sections, *i.e.* northern, (middle), and southern. Polar desert which had an extremely low vegetative cover was also divided into northern and southern sub-sections.

For the present study, geographic division of the Canadian arctic basically follows BLISS (1977).

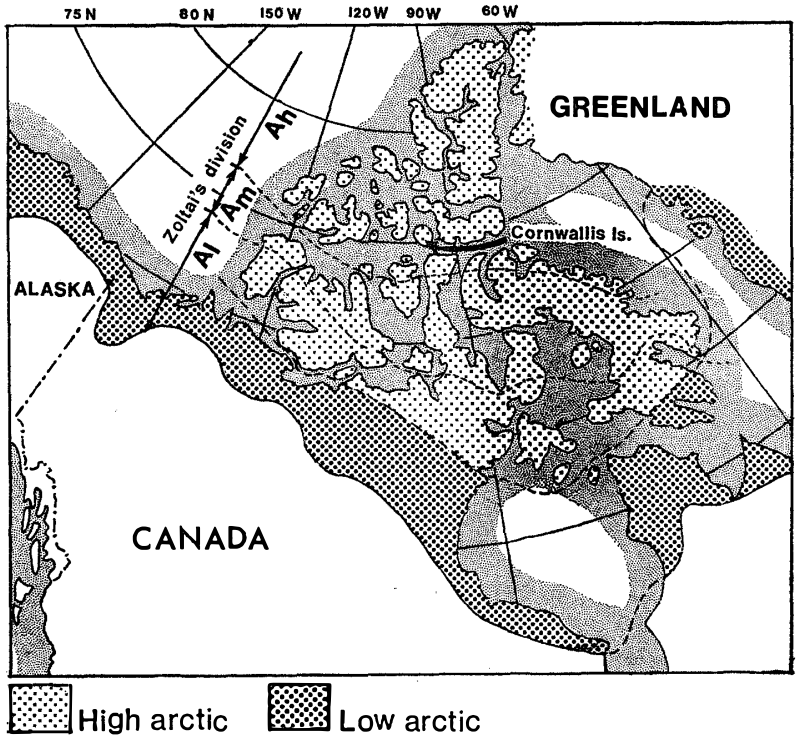

Fig. 1. Geographical division of the Canadian arctic (after BLISS, *1977) and the location of Cornwallis Island. The map also shows* ZOLTAI*'s division with broken lines: Ah: high arctic, Am: mid arctic, Al: low arctic.*

3. Study Area and Methods

3.1. Study area

The study area is located in the southwestern part of Cornwallis Island. Latitudinally it is located *ca.* 74°40′–75°00′N, and longitudinally *ca.* 94°30′–95°30′W. It is situated in the center of the high arctic (Fig. 1). Terrain configuration is generally low and gently undulating with an elevational range from 0 (sea shore) to 100 m above sea level approximately. The highest peak in the island is 350 m asl. Geologically, the entire area is covered with sedimentary rocks of the Ordovician to Silurian. Lithologically these rocks consist predominantly of limestone, argillaceous limestone, dolomite, and calcareous shale (THORSTEINSSON and KERR, 1968). Climate of the area is extremely frigid and dry (ATMOSPHERIC ENVIRONMENT SERVICE, 1982). At Resolute Bay, the

Table 2 Climatic characteristics of the

Item	Month Jan	Feb	Mar	Apr
Mean monthly temperature (°C)	−32.1	−33.3	−31.4	−23.1
Mean monthly aximum temperature	−28.4	−29.6	−27.8	−19.2
Mean monthly minimum temperature	−35.7	−36.8	−35.0	−27.0
Extreme maximum temperature	− 0.8	− 3.9	−6.7	0.0
Extreme minimum temperature	−52.2	−52.0	−51.7	−41.7
Mean total precipitation (mm)	3.3	3.0	3.0	5.9

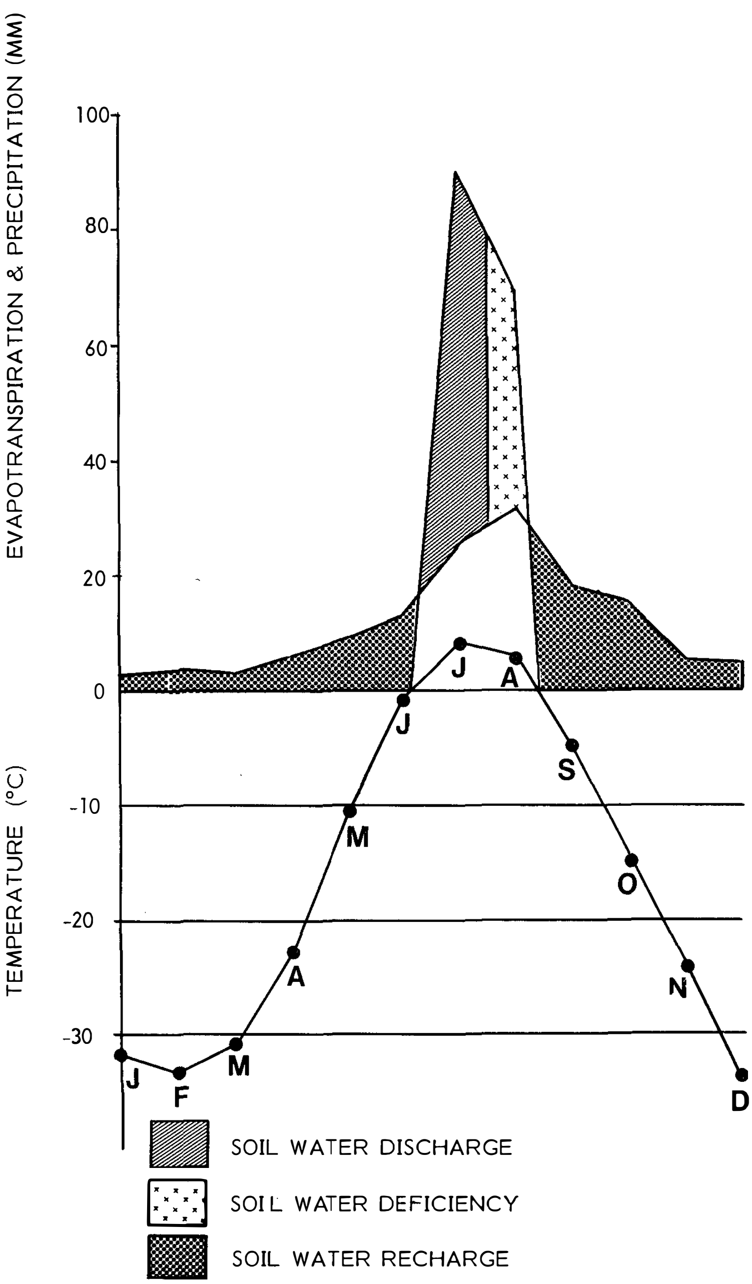

Fig. 2. Climatic characteristics of Resolute according to THORNTHWAITE's (1948) formula. The diagram evidently shows water deficit taking place in July and August.

study area as represented by Resolute.

May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
−10.9	−0.6	4.1	2.4	−5.1	−15.1	−24.5	−29.3	−16.9
−7.7	1.7	6.8	4.7	−2.9	−12.0	−20.9	−25.7	−13.4
−14.1	−2.9	1.4	−0.1	−7.2	−18.3	−28.0	−32.9	−19.7
4.4	13.9	18.3	15.0	9.4	0.0	− 2.8	−6.1	18.3
−29.4	−16.7	−2.8	−8.3	−20.6	−35.0	−42.8	−46.1	−52.2
8.1	12.1	22.5	31.1	18.0	13.8	5.7	4.9	131.4

central community of the island, mean annual tempreature is −16.9°C, with mean monthly temperature of the coldest month −32.1°C, and that of the warmest month 4.1°C, with two months of mean monthly temperature above 0°C. Such a climate is designated as ET after KÖPPEN (1936). Mean annual total precipitation is 131 mm. About 40% of it comes in summer (July and August). Snow is quite common even in midsummer. Table 2 summarizes the climatic characteristics of the island. Figure 2 illustrates the climate according to THORNTHWAITE (1948).

In most instances, soils are extremely coarse. Horizonation is not well developed due to almost lack of leaching, extremely sparse vegetative cover, and intense cryoturbation as well as thermokarst. Accumulation of organic matter is very low. Such soils are generally called polar desert soil (TEDROW, 1968; CHARLIER, 1969). Under sedge meadows, however, hydromorphic soils develop, which show a fair horizon development with a relatively thick organic layer. Permafrost is continuous, though in most instances it is not visibly detectable because of extremely coarse substrates. However, when temperature is measured, it is below 0°C at the depth of 40–50 cm in midsummer. When organic matter accumulates, which is the case of sedge meadows, permafrost is always discernible at the depth of *ca.* 20–40 cm in midsummer. Soils are highly calcareous because of the limestone parent material and a lack of strong leaching due to the small amount of precipitation and practically year-round freezing conditions. Soil reaction (pH) always exceeds 7.0 with the highest pH 7.8 (CRUICKSHANK, 1971). Chemical weathering is expected low (MCMILLAN, 1960) due to the low temperature,

Fig. 3. Polar desert landscape showing an extremely sparse vegetation of the high arctic.

Fig. 4. A Carex stans *community. When vegetation develops in well-moist habitats, it shows a high vegetative cover even in the generally harsh environment of the high arctic.*

a small amount of precipitation, and low rate of organic matter production and decomposition. Patterned ground is a very common feature. Most soils of the area may be regarded as polar desert soil, which may be comparable to rawmark soil of KUBIENA (1953). CRUICKSHANK (1971) recognized three basic types of soils: Polar Desert, Lithosol and Tundra gley, and considered the first type most dominant. Such soils may be classified as Regosolic Turbic Cryosol of the Canadian soil classification system (CANADIAN SOIL SURVEY COMMITTEE, 1978).

Vegetation is best represented by "polar desert" (Fig. 3) with sporadic occurrences of such vascular species as *Dryas integrifolia, Saxifraga oppositifolia, Papaver lapponicum, Minuartia rossii, Draba bellii, Salix arctica, Cerastium regelii, Stellaria longipes, Poa arctica, Festuca baffinensis, Juncus biglumis,* and *Luzula arctica.* Most of them form tufts, cushions or rosetts. Vegetative cover is extremely low as it is less than 5% in most cases, thus creating a characteristic barren landscape which may be called polar desert. Lichens and bryophytes are always present. Lichens tend to dominate over bryophytes when habitats are dry and stony while bryophytes become dominating in moist habitats. Sedge meadow develops in very moist habitats along streams or seepage sites. It is a dense and species-rich vegetation dominated usually by *Carex stans* (Fig. 4).

3.2. Field investigation procedures

After an extensive reconnaissance, sampling plots of 5 m × 5 m quadrat were estab-

Table 3. DOMIN-KRAJINA's species significance class (KRAJINA, 1933).

Class	Description
+	Solitary, very low dominance (0–1%)
1	Seldom, very low dominance (1–2%)
2	Very scattered, low dominance (2–3%)
3	Scattered, low dominance (3–5%)
4	Covering 5–10% of the plot
5	Covering 10–20% of the plot
6	Covering 20–33% of the plot
7	Covering 33–50% of the plot
8	Covering 50–75% of the plot
9	Covering more than 75% but less than 100% of the plot
10	Covering 100% of the plot

lished to represent vegetation. Plot sites were selected subjectively to obtain as much different kinds of vegetation as possible efficiently in a limited time. At each plot, all the vascular plants in the quadrat were listed and their coverage was assessed in DOMIN-KRAJINA species significance class (Table 3). For the bryophytes and lichens, a composite coverage was assessed. Specimens of plants which were not identified in the field were collected for determination in the laboratory. One soil pit was dug for each plot to the depth of 50 cm or to the depth of permafrost table whichever shallower. Profile was observed and described. Moisture was rated subjectively by hand-feeling in five classes, *i.e.* xeric, subxeric, mesic, hygric, and hydric. Stoniness of the habitat was also rated in five classes based on the amount of stones (more than 5 mm in grain diameter) which cover the ground surface. Field investigation was conducted in late July 1981. A total of fifty-one plots were established.

3.3. *Laboratory procedures and data synthesis*

All the plot data was assembled and manually classified according to the conventional phytosociological procedures (BRAUN-BLANQUET, 1932). Vegetation was classified and vegetation synthesis tables were constructed for each vegetation type. A synoptic table was also constructed based on the data abstracted from the synthesis tables.

Similarity indices were calculated for all the combinations of the vegetation types according to the calculation methods of SØRENSEN (1948) as modified by DAHL (1956), *i.e.*,

$$SI=2C/(A+B)$$

where SI: similarity index
A: sum of the species significance class of all the species in plot A,
B: sum of the species significance class of all the species in plot B,
C: sum of the smaller species significance class of the species common both to the plots A and B.

A dendrogram was constructed using the similarity indices.

Edaphic conditions in terms of soil moisture regime and stoniness of habitat were correlated with the vegetation types to find ecological relations between the vegetation and edaphic conditions.

In this paper, epithets of vascular plants mainly refer to HULTÉN (1968), and some to PORSILD (1964). Determination of bryophytes and lichens was made by D. J. JOHNSON of the Northern Forest Research Centre, Canadian Forestry Service, in Edmonton.

4. Results and Discussion

4.1. Vegetation classification

Based on vegetation structure of the fifty-one plots, seven vegetation types were recognized (Table 4). They were: 1. *Saxifraga caespitosa-Poa arctica* type, 2. *Saxifraga oppositifolia-Draba bellii* type, 3. *Saxifraga oppositifolia-Festuca baffinensis* type, 4. *Saxifraga oppositifolia-Salix arctica* type, 5. *Saxifraga oppositifolia-Dryas integrifolia* type, 6. *Dupontia fisheri-Alopecurus alpinus* type, and 7. *Carex stans* type. In this study, vegetation type was defined as a plant association (*sensu* KRAJINA, 1960), *i.e.* the smallest classification unit discriminable vegetationally as well as environmentally. A vegetation synthesis table was constructed for each vegetation type. The following are brief descriptions of the types.

1) *Saxifraga caespitosa-Poa arctica* type (=*Saxifraga caespitosa* type)

This vegetation type is characterized by the presence of *Saxifraga caespitosa*, *Papaver lapponicum*, *Poa arctica*, and *Minuartia rossii*. Other major species include *Juncus biglumis*, *Saxifraga cernua*, and *S. oppositifolia*. Vegetative cover is very low. It is *ca.* 3% on the average. Total number of vascular species is small as it ranges from 7 to 12 with an average of 9.0 species. Total cover of cryptogams (bryophytes and lichens) is also low with an average of less than 1%. In general, lichens such as *Thamnolia subuliformis*, *Alectoria ochroleuca*, *Cetraria islandica*, *Cornicularia divergens*, and *Stereocaulon* sp. are more prevalent than bryophytes.

This type represents vegetation on coarse polygonal patterned ground. Polygons of *ca.* 1 m in diameter on the average consist of sorted stones encircling fine earth in the centers where scattered vascular plants grow. It is comparable to the Moss-Herb type described from nearby Devon Island by MUC and BLISS (1977), and to the *Saxifraga-Papaver* community from Somerset and Prince Wales Islands described by WOO and ZOLTAI (1977).

2) *Saxifraga oppositifolia-Draba bellii* type (=*Draba* type)

This vegetation type is characterized by the presence of *Saxifraga oppositifolia*, *Papaver lapponicum*, *Draba bellii*, and *Poa arctica*. *Saxifraga oppositifolia* dominates the vegetation. Other major species include *Minuartia rossii*, and *Cerastium beeringianum*. Vegetative cover is low as it is 4% on the average. Total number of vascular species is also low as it is 6.9 on the average ranging from 5 to 9 species. Total cover of cryptogams is low with an average of 2%. Lichens such as *Thamnolia subuliformis*, *Cornicularia divergens*, *Dactylina arctica*, and *Stereocaulon* sp. are dominating over bryophytes.

This type occurs on rock barren with very coarse substrates. Soils are typically of Polar Desert of CRUICKSHANK (1971). The vegetation type is comparable to the Moss-Herb type of MUC and BLISS (1977), *Saxifraga-Draba* community of WOO and ZOLTAI (1977), and barren heath subtype of ZOLTAI *et al.* (1981).

Table 4. A synoptic constancy table of vascular plants.

Vegetation type No.*	1	2	3	4	5	6	7
Number of plots	8	7	5	6	10	8	7
Order**	So					Cs	
Alliance***	Pl			Sa		Cs	
Species							
Saxifraga oppositifolia	**III**	**V**	**V**	**V**	**V**	·	·
Minuartia rossii	**IV**	**III**	**IV**	II	II	II	II
Papaver lapponicum	**V**	**V**	**V**	II	III	I	I
Poa arctica	**V**	**IV**	**III**	·	·	·	·
Saxifraga caespitosa	**V**	I	II	·	I	I	·
Draba bellii	**III**	**V**	**IV**	II	II	II	·
Parrya arctica	II	**III**	II	·	I	·	·
Festuca baffinensis	·	·	**V**	·	·	·	·
Cerastium beeringianum	II	**III**	**IV**	·	I	·	·
Arenaria sajanensis	·	II	**III**	·	·	·	·
Salix arctica	I	·	II	V	V	IV	V
Eutrema edwardsii	·	·	I	**III**	·	·	·
Dryas integrifolia	·	·	·	·	V	·	·
Carex stans	·	·	·	·	·	**II**	**V**
Saxifraga hirculus	·	·	·	·	·	**V**	**V**
Draba lactea	·	·	·	·	·	**IV**	**V**
Dupontia fisheri	·	·	·	I	·	**V**	**V**
Saxifraga cernua	III	II	·	·	·	**IV**	II
Cerastium regelii	II	II	II	I	·	**IV**	·
Alopecurus alpinus	II	·	·	·	·	**IV**	·
Stellaria longipes	II	I	III	II	·	**V**	**V**
Juncus biglumis	III	·	I	III	·	**IV**	**V**
Melandrium apetalum ssp. *arcticum*	·	·	·	·	·	**III**	**V**
Carex membranacea	·	·	·	·	·	·	**V**
Luzula arctica	II	·	III	I	·	II	**IV**
Eriophorum angustifolium	·	·	·	·	·	II	**IV**
Carex misandra	·	·	·	I	I	·	**III**
Polygonum viviparum	·	·	·	I	·	I	**III**
Average number of vascular species	9.0	6.9	10.4	6.0	5.2	11.5	12.4
Averaged total cover of cryptogams (%)	+	2	26	82	2	44	52
Averaged total vegetative cover (%)	3	4	64	100	10	97	100

* Vegetation type Nos. 1: *Saxifraga caespitosa* type, 2: *Draba bellii* types, 3: *Festuca baffinensis* type, 4: *Salix arctica* type, 5: *Dryas integrifolia* type, 6: *Dupontia fisheri* type, 7: *Carex stans* type.

** So: Saxifragetalia oppositifoliae, Cs: Caricetalia stanis.

*** Pl: Papaverion lapponici, Sa: Salicion arcticae, Cs: Caricion stanis.

Roman numerals represent constancy class. Those enclosed in frames indicate the characteristic species of the order and alliance. Those in bold face indicate characteristic combinations of species for the vegetation types.

3) *Saxifraga oppositifolia-Festuca baffinensis* type (=*Festuca* type)

This vegetation type is characterized by the presence of *Saxifraga oppositifolia*, *Papaver lapponicum*, *Festuca baffinensis*, *Cerastium beeringianum*, *Minuartia rossii*, and *Draba bellii*. Other major species include *Poa arctica*, *Luzula arctica*, *Arenaria sajanensis*, and *Stellaria longipes*. It occurs in habitats of relatively fine soils with comparatively better moisture supply. Total number of vascular species is moderate as it is 10.4 on the average ranging from 7 to 14. Vegetative cover is also moderate. It is 64% on the average. Total cover of cryptogams is also moderate as it is 26% on the average. In this type, bryophytes dominate over lichens. Major bryophytes include *Ditrichum flexicaule*, *Hypnum bambergeri*, and *Tortula ruralis*.

This type is comparable to *Saxifraga-Papaver* community of Woo and Zoltai (1977).

4) *Saxifraga oppositifolia-Salix arctica* type (=*Salix* type)

This vegetation type is characterized by the presence of *Salix arctica*, *Saxifraga oppositifolia*, and *Juncus biglumis*. *Salix arctica* which shows a fair dominance usually forms low prostrating mats of various sizes. Other major species include *Papaver lapponicum* and *Eutrema edwardsii*. This type develops, covering an extensive area, in moderately moist habitats with fine soils on hummocky polygonal ground. Figure 5 illustrates a cross section of a hummock. Total number of vascular species is low as it is 6.0 on the average ranging from 4 to 7. And yet, vegetative cover is very high as it attains to 100%. Such a high coverage is actually much contributed by cryptogams as the total cover of cryptogams is 82% on the average. Major bryophytes include *Ditrichum flexicaule*, *Distichium capillaceum*, *Hypnum bambergeri*, *Orthothecium chryseum*, *Catoscopium nigritum*, and *Drepanocladus revolvens*. Crustose lichens completely cover the surface of hummocks of fine earth.

This type is comparable to the *Saxifraga-Salix* community of Woo and Zoltai (1977).

5) *Saxifraga oppositifolia-Dryas integrifolia* type (=*Dryas* type)

This vegetation type is characterized by the presence of *Saxifraga oppositifolia*,

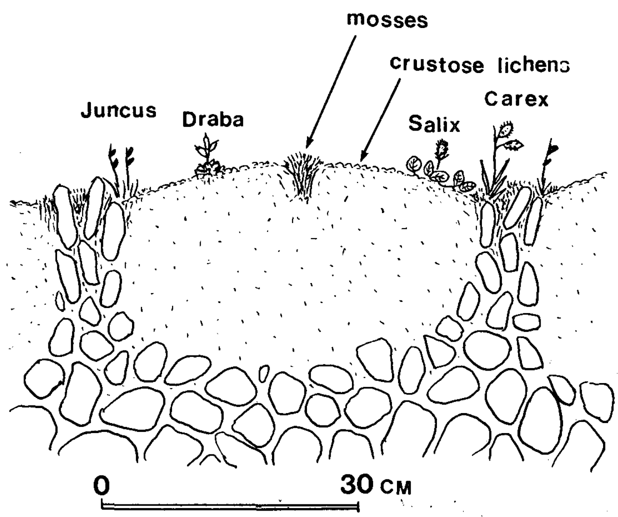

Fig. 5. A diagram showing a cross section of a polygonal hummock. Platy stone vertically positioned border the plygonal hummocks.

Salix arctica, and *Dryas integrifolia*. Other major species includes *Papaver lapponicum*. *Dryas integrifolia* typically forms cushions of various sizes. Cushions are distributed very sparsely and in usual cases their diameter ranges from *ca.* 20 to 40 cm (Fig. 6). It occurs in habitats of coarse substrates but with slightly moist soils. Total number of vascular species is small as it is 5.2 ranging from 4 to 8 species, which is indeed the smallest number. Vegetative cover is also low as it is 10% on the average. Total cover of cryptogams is also low as it is 2% on the average. Lichens show slightly higher coverage than bryophytes. Major lichens include *Thamnolia subuliformis*, *Lecanora epibryon*, *Cetraria cucullata*, *Stereocaulon* sp., and *Cornicularia aculeata*. Major bryophytes are *Ditrichum flexicaule*, *Hypnum bambergeri*, *Orthothecium chryseum*, *Tortula ruralis*, and *Distichium capillaceum*. This type occurs very widely in the study area. It is, therefore, the type which, so to speak, best represents the vegetation of the study area.

This type is comparable to the cushion plants-lichen type of MUC and BLISS (1977), *Saxifraga-Dryas* community of WOO and ZOLTAI (1977), and *Dryas* barren subtype of ZOLTAI *et al.* (1981).

6) *Dupontia fisheri-Alopecurus alpinus* type (=*Dupontia* type)

This vegetation type is characterized by the presence of *Dupontia fisheri*, *Alopecurus alpinus*, *Saxifraga hirculus*, *Stellaria longipes*, *Juncus biglumis*, *Draba lactea*, *Cerastium regelii*, *Saxifraga cernua*, and *Salix arctica*. Other major species include *Melandrium*

Fig. 6. Sporadic occurrences of cushion plants. Such cushions are usuallly formed of Dryas integrifolia. *This kind of vegetation best represents those in the high arctic environment of the study area.*

apetalum and *Eriophorum angustifolium*. Total number of vascular species is large as it is 11.5 on the average ranging from 8 to 15. Vegetative cover is high as it is 97% on the average, which consists mainly of vascular plants. Total coverage of cryptogams predominantly of bryophytes is moderate as it is 44% on the average. Major bryophytes include *Distichium capillaceum*, *Cinclidium arcticum*, *Drepanocladus revolvens*, *Orthothecium chryseum*, *Pogonatum alpinum*, *Bryum pseudotriquetrum*, *Catoscopium nigritum*, *Tomenthypnum nitens*, and *Philonotis fontana*. Lichens such as *Cetraria cucullata*, *Cladonia amaurocraea* and *Lecanora epibryon* are present but less dominant.

It develops in seepage habitats where water is seeping and slowly moving. It usually occurs at slope base, small stream beds, and along lake shore. In general, soils are stony and coarse-textured (Fig. 7) and usually saturated with water. Such soils are designated as Tundra gley soil by CRUICKSHANK (1971).

This type is comparable to the hummocky graminoid meadow of MUC and BLISS (1977). It resembles the Eriophoro-Salico-Arctagrostidetum latifoliae of BARRETT (1972).

7) *Carex stans* type (= *Carex* type)

This vegetation type is characterized by the presence of *Carex stans*, *Dupontia fisheri*, *Carex membranacea*, *Saxifraga hirculus*, *Salix arctica*, *Draba lactea*, *Juncus biglumis*, *Eriophorum angustifolium*, *Stellaria longipes*, *Luzula arctica*, and *Melandrium apetalum*. *Carex stans* is a dominant. Other major species include *Carex misandra* and *Polygonum viviparum*. It is somewhat similar to the *Dupontia* type described above. But it is distinguished from it with much higher dominance of *Carex stans*, and higher constancy of *Carex membranacea*, *Luzula arctica*, and *Eriophorum angustifolium*. It develops in wet habitats where soils are saturated with water. Moving water is observed in most instances. Soils are rather fine-textured. Peat accumulation is noticeable though it is not necessarily thick (Fig. 7). This type of soils is regarded as Bog soil by CRUICKSHANK (1971).

This type is characteristically rich in vascular plants as total number of vascular species is 12.4 ranging from 10 to 15, which is the largest number of all the vegetation types. Total cover of cryptogams is high as it is 53% on the average, which consists

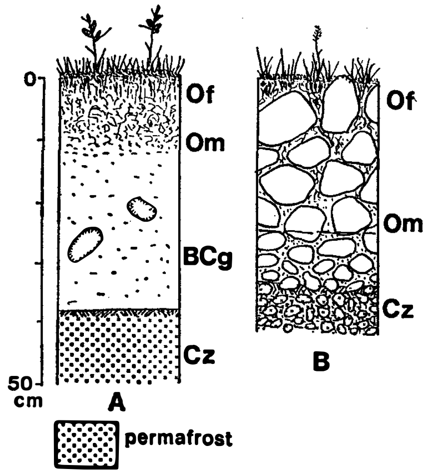

Fig. 7. Diagramatic sketches of soil profiles. A: a profile of the Carex stans *type consisting of relatively fine earth, B: a profile of* Duponita *type consisting of coarse material.*

predominantly of bryophytes. Major bryophytes include *Drepanocladus revolvens*, *Cinclidium arcticum*, *Orthothecium chryseum*, *Distichium capillaseum*, *Scorpidium turgescens*, *Catoscopium nigritum*, *Philonotis fontana*, *Blepharostoma trichophyllum*, and *Myurella julacea*.

This type occurs commonly throughout the study area in habitats of lake shore, stream beds, and slope bases. It represents the so-called sedge meadow vegetation. It is comparable to Caricetum stanis of BARRETT (1972), to the hummocky sedge-moss meadow of MUC and BLISS (1977), to the *Carex-Hierochloe* community of WOO and ZOLTAI (1977), and sedge meadow subtype of ZOLTAI *et al.* (1981).

4.2. *A synsystematic hierarchy of the vegetation*

An attempt was made to apply a conventional phytosociological classification hierarchy (BRAUN-BLANQUET, 1932) to the vegetation of the study area. Assuming that each vegetation type described above was to represent a plant association, then seven

Table 5. Phytosociological hierarchy of vegetation of the study area.

Association	Alliance	Order
1. Saxifragetum caespitosae	Papaverion lapponici	Saxifragetalia oppositifoliae
2. Drabetum belli		
3. Festucetum baffinensis		
4. Salicetum arcticae	Salicion arcticae	
5. Dryetetum integrifoliae		
6. Dupontio-Alopecuretum alpini	Caricion stanis	Caricetalia stanis
7. Caricetum stanis		

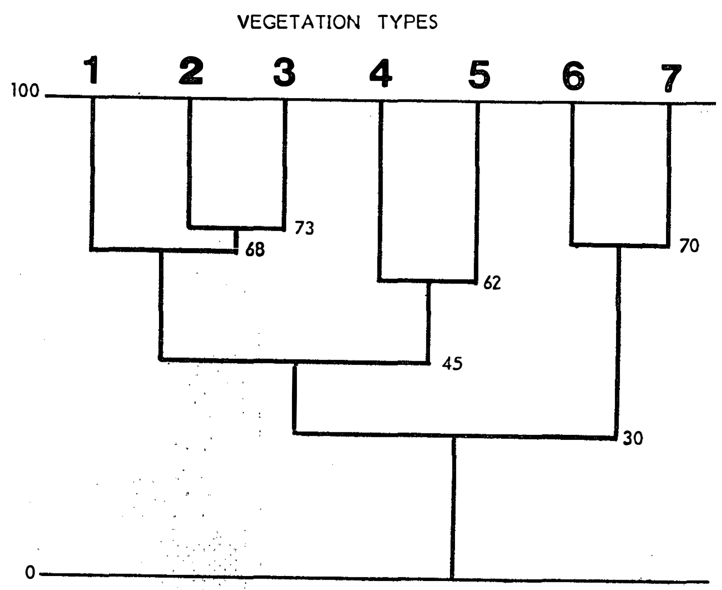

Fig. 8. A dendrogram showing vegetational affinities of the seven vegetation types. The numerals indicate vegetation similarity indices at which the vegetation types or groups of vegetation types are linked.

associations (=vegetation types) were recognized. They were grouped into three alliances and the alliances further into two orders. Table 5 presents the hierarchy of the classification.

Based on the data presented in Table 4, a dendrogram was constructed (Fig. 8). When the dendrogram was compared with the phytosociological hierarchy in Table 5, one will notice that the clustering of the dendrogram closely corresponds to it. The diagram clearly shows three groups of vegetation, *i.e.* the first group consisting of vegetation types 1, 2, and 3, the second group of vegetation types 4 and 5, and the third group of vegetation types 6 and 7. These groups are comparable to alliance of phytosociology. Thus the first group of the clustering corresponds to Papaverion lapponici, the second group to Salicion arcticae, and the third group to Caricion stanis. The first and second groups are further lumped together to form a higher classification unit Saxifragetalia oppositifoliae. The third group stands for itself to correspond to Carisetalia stanis.

4.3. Vegetation differentiation and environment relationships

It was presupposed that, under the same macroclimate of KÖPPEN's ET and within a homogeneous geology that was predominantly of limestone, local site specific edaphic

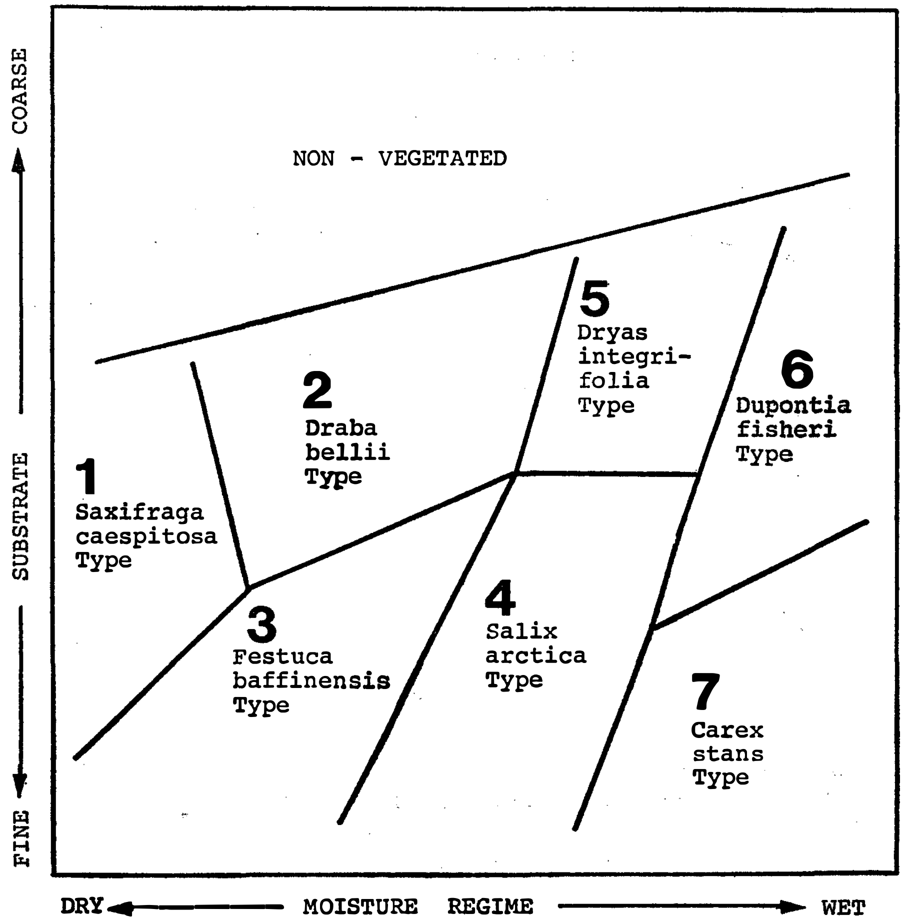

Fig. 9. A conceptual diagram showing vegetation differentiation in relation to edaphic conditions in terms of soil moisture and coarseness of substrates.

conditions seemed to have had pronounced effects on differentiation and establishment of the vegetation types. The edaphic conditions were recorded in terms of moisture regime and stoniness of the habitats. These factors were related with the vegetation types.

Figure 9 schematically illustrates the vegetation differentiation of the study area in relation to edaphic conditions in terms of moisture regime and stoniness (or coarseness of substrates). Vegetation development seemed to have been much affected by moisture availability. As long as a sufficient amount of moisture is supplied, plants can grow even in fairly stony habitats, but they are confined to habitats with fine soils when moisture availability is limited. At the same time one might notice that vegetative cover as well as total number of species also become higher when habitat becomes more moist. Thus, habitats of extremely dry and coarse substrates are virtually non-vegetated as far as vascular plants are concerned. Figure 10 shows an ecological range of high vegetative cover in relation to the vegetation types and edaphic conditions.

It is then quite conceivable that the very sparse vegetation of the high arctic which

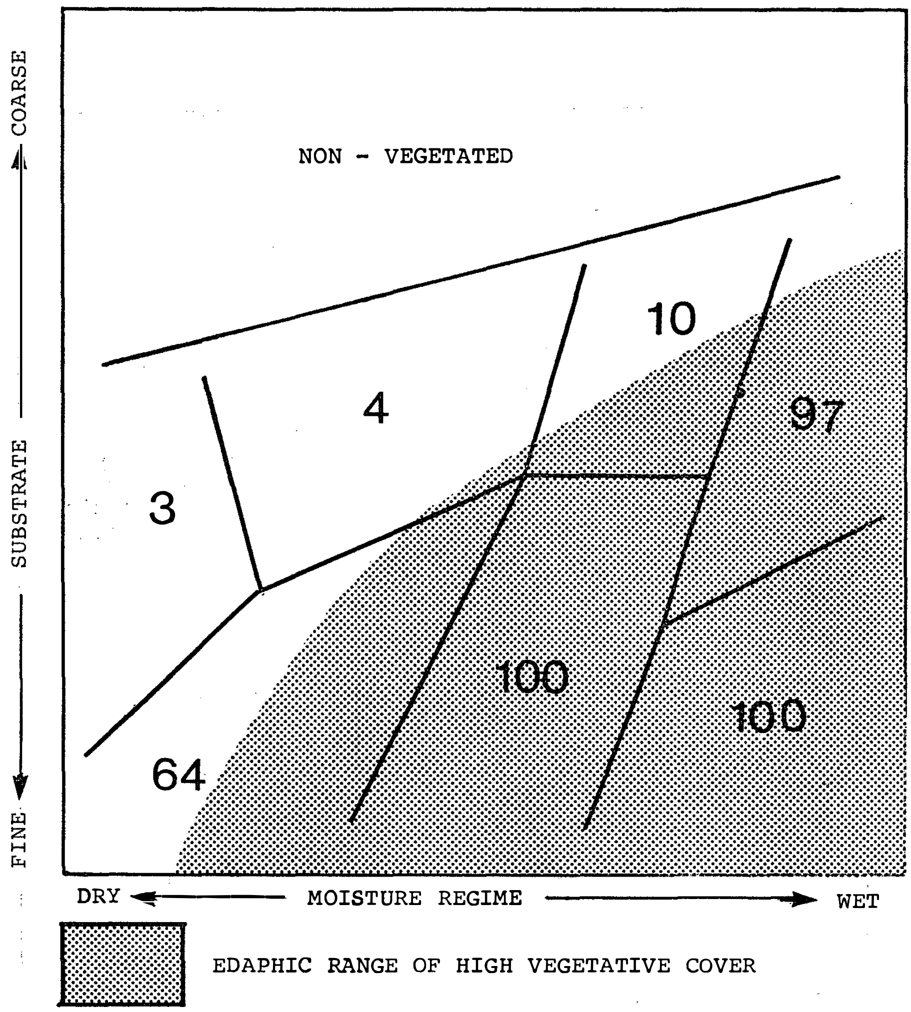

Fig. 10. An ecological range of high vegetative cover in relation to the edaphic conditions and vegetation types. The numbers indicate averaged vegetative cover in percent.

is customarily called polar desert is in fact substantiated by a lack of sufficient supply of moisture. As long as ample supply of moisture is guaranteed, luxurious growth of vegetation is possible as exemplified in the *Carex stans* type and *Dupontia fisheri* type. In other words, shortage of moisture seems to be an important factor to maintain the barren landscape of the high arctic.

Indeed, climate of the area is arid enough to substantiate the desert-like landscape. When calculated according to THORNTHWAITE's formula (THORNTHWAITE, 1948), the climate of the area evidently shows a considerable water deficit which takes place in summer (Fig. 2). Furthermore, the calculation assumes soils water storage of 100 mm. Howevei, majority of the soils in the study area is actually very stony and coarse-textured. It is unlikely that most soils of the area can hold so much of moisture. Then water deficit will become a much serious condition for plants. This is one of the critical factors to discourage the development of luxurious growth of vegetation. In the study area, habitats with ample supply of water are rather limited to small areas of seepage discharge sites, lake shore, small stream beds, etc. A large extent of the area is indeed covered by extremely stony terrain such as fell-field. This is why the barren landscape develops so extensive to characterize the physiognomy of the study area, which is called polar desert.

Althought it is no question that the arid climate is a prime factor to substantiate the barren landscape of the area, geology may also act to some extent as an agent to generate the sparse vegetation. An extensive occurrence of limestone which is hard and resistant to weathering may create difficult conditions for plant establishment. Limestone substrates also provide strongly alkaline soils with excess of basic cations, on which only calcicolous plants can get well established. In fact, WOO and ZOLTAI (1977) showed a striking contrast of vegetation development due to different geological substrates in high arctic. On less alkaline sandstone substrate, vegetation develops well with high vegetative cover whereas on limestone substrate an extremely sparse vegetation occurs even under the same macroclimatic conditions. Vegetation of the area is in fact to represent limestone vegetation. Vascular flora of the area includes a considerable amount of calcicolous plants. Majority of the species shown in Table 4 are indeed calcicolous (KOJIMA and BROOKE, 1985; BROOKE and KOJIMA, 1985). The phytosociological order Saxifragetalia oppositifolia described above is in fact to represent a limestone vegetation under a frigid climate. In Spitzbergen, ACOCK (1940) recognized common occurrences of *Saxifraga oppositifolia* in calcareous habitats where soils were alkaline with pH ranging from 7.4 to 8.4.

Another possible factor to substantiate the desolate landscape may be a shortage of nutrients especially of nitrogen and phosphorus as was pointed out (WOO and ZOLTAI, 1977). Indeed, even within the extensive barren landscape, vegetation occasionally shows much better growth with a high vegetative cover locally in such sites as around lemming and fox dens, bird perch sites, and near human habitations, where a plenty supply of nutrients is expected. The author has indeed witnessed extremely lush growth of vegetation along a water channel collecting sewage from industrial area nearby the Resolute Airport (Fig. 11).

It may be thus concluded that the barren landscape called polar desert is in fact substantiated by a shortage of moisture supply synergistically with low temperature.

Fig. 11. A lush growth of vegetation in habitat which is eutrophicated with sewage discharge.

The low temperature alone acts as a factor preventing tree and tall shrub species from establishing there to substantiate treeless landscape but not necessarily creating the polar desert.

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