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RELATIONSHIPS OF VEGETATION, EARTH HUMMOCKS, AND TOPOGRAPHY IN THE HIGH ARCTIC ENVIRONMENT OF CANADA

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Abstract: Relationships of vegetation, earth hummocks, and topography were studied in the high arctic environment of Ellesmere Island, N.W.T., Canada. A belt-transect 2 m wide and 114 m long was established on a south-west facing slope of a small knoll, where well developed earth hummocks were recognized. The belt-transect was sectioned in 2 m × 2 m successive quadrats. For each quadrat, cover degree of individual species and total vegetation was assessed and recorded. After earth hummocks were categorized conveniently into three types according to a degree of being covered by vegetation, the number of earth hummocks in each quadrat was counted for each type. A topographical cross-section along the belt-transect was surveyed, and vegetation and earth hummock characteristics were correlated with topographical position. Well developed earth hummocks were recognized mainly at the base of a leeward slope of the knoll where snow possibly drifted and stayed long enough to protect vegetation and earth hummocks from strong wind, especially in winter. Vegetation, too, developed well in places where earth hummocks developed well; it consisted predominantly of *Salix arctica, Saxifraga oppositifolia, Poa abbreviata, Dryas integrifolia,* and *Pedicularis arctica.* Development of the earth hummocks was regarded as a synergistic product of such factors as fine soil material, topography, snow, permafrost, and vegetation. Snow was considered to play a decisive role in developing and maintaining well developed earth hummocks and vegetation by protecting them from adverse wind effects in winter. This is why the majority of the well developed earth hummocks are confined to leeward slope-bases where wind blown snow accumulates and stays relatively long.

1. Introduction

In the High Arctic, periglacial ground structuring is very intense and widespread. There vegetation and soil development are necessarily regulated by the periglacial activities to generate various characteristic landforms and landscapes. Earth hummock is one of the very common periglacial ground configurations in the Arctic and Subarctic (TARNOCAI and ZOLTAI, 1978). It is a soil mound regularly interspaced. WASHBURN (1956) calls it "nonsorted nets". Its height usually ranges from 20–50 cm and occasionally becomes as large as 1–2 m; the diameter is of the same magnitude (WASHBURN, 1956; FRENCH, 1976). Earth hummocks always occur in large groups. They are likely formed when soils thaw or freeze by hydrostatic or cryostatic pressure which transfers fine soil material upward to form a mound-shape with a convex round top (LUNDQVIST, 1969).

There are a number of studies which describe arctic vegetation in relation to edaphic conditions. Some of them are: ACOCK (1940), HANSON (1950), BARRETT (1972), WOO and ZOLTAI (1977), ZOLTAI and JOHNSON (1978), PETERSON *et al.* (1981), BLISS *et al.* (1984), SOHLBERG and BLISS (1984), MILLER and ALPERT (1984), THANNHEISER (1988, 1989, 1990), BERGERON and SVOBODA (1989), KOJIMA (1991), and MAYCOCK and FAHSELT (1992). But not many studies specifically deal with the relationships between vegetation and earth hummocks. The objectives of the present study are 1) to describe vegetation developing in earth hummock terrain, 2) to analyze vegetation and earth hummock relationships, and 3) to present an ecological interpretation as to the interrelations of vegetation, earth hummocks, and topography in the high arctic environment.

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2. Study Area and Study Site

The study area is located in Sverdrup Pass (79°08′N, 80°30′W, 300 m above sea level), Ellesmere Island, N.W.T., Canada (Fig. 1). It typically belongs to the High Arctic region of BLISS (1977) where polar desert landscapes extend widely (Fig. 2). Climate as represented by the weather station at Eureka is extremely harsh (Table 1). Such a climate is classified as ET after KÖPPEN (1936). The area

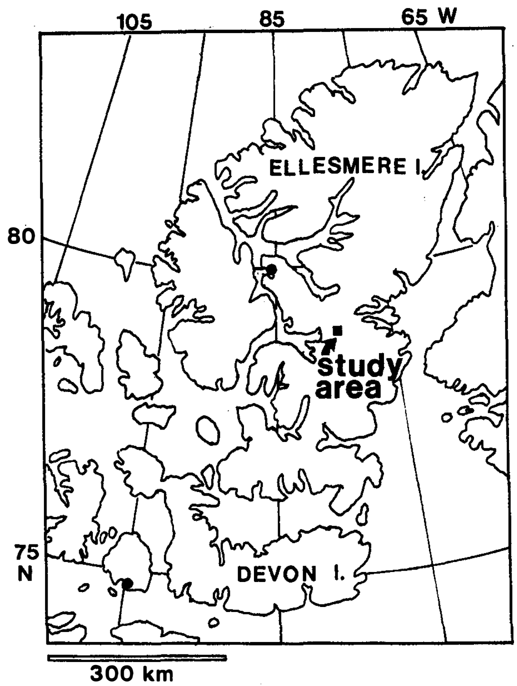

Fig. 1. The geographical location of the study area.

Fig. 2. General view of the polar desert landscape in Sverdrup Pass.

Table 1. Climate of the study area as approximated by the Weather Station at Eureka (80°00′ N, 85°56′ W) (ATMOSPHERIC ENVIRONMENTAL SERVICE, 1982)

Month	1	2	3	4	5	6	7	8	9	10	11	12	year
MMT (°C)	−36.4	−38.0	−37.4	−27.6	−10.7	1.8	5.4	3.3	−8.3	−22.1	−31.5	−34.6	−19.7
MMTP (mm)	3	2	2	3	3	5	12	12	10	7	3	2	64

MMT: mean monthly temperature, MMTP: mean monthly total precipitation

is characteristically windy, as it is located in a narrow wind corridor connecting the east and west coasts of the island. Predominant geology consists of limestone and dolomite of the Upper Ordovician and Lower Devonian with sporadic occurrences of granitic gneiss of the Canadian Shield (THORSTEINSSON and TOZER, 1970). Soils are generally coarse and highly calcareous. Horizons poorly develop due to intense physical weathering, strong cryoturbation, and a small amount of precipitation. The majority of the soils are regosolic turbic or regosolic static cryosols of the Canadian Soil Classification System (CANADIAN SOIL SURVEY COMMITTEE, 1978), which may be comparable to the polar desert soil of TEDROW (1966, 1977) and CHARLIER (1969), and arctic rawmark or arctic hamada of KUBIENA (1953). Vegetative cover is very low. In most instances, it is less than 5% of the ground surface except for some wet meadows.

The study site is situated in a bottom of a broad and flat glacier valley of a general east-west trend. In the very bottom of the valley, there is a little knoll of drumlin origin. Its height is *ca.* 10–15 m. It is conspicuously projecting from surrounding level ground. At the base of the hill which is facing southwest, remarkably well developed earth hummocks are recognized (Fig. 3). The hummocks are generally 15–60 cm in diameter and approximately 20–50 cm in height.

Fig. 3. Well developed earth hummocks. Such hummocks were concentrated in a leeward slope base of a small hill.

Most of them are covered by vegetation which is co-dominated by *Salix arctica* and *Dryas integrifolia* to a varying degree, though some are bare at their top portions. Development of the earth hummocks seems to be rather confined near the base of the leeward slope and absent on upper slopes of the knoll as well as at the very bottom of the slope. They poorly develop on slopes of other aspects. Vegetation characteristics change substantially depending on slope position from the base to the top to constitute a series of vegetation belts which stretch roughly parallel to the contour. Vegetative cover of vascular plants, which is low on level ground surrounding the hill, increases considerably toward the lower slopes but decreases again on the upper slopes. It becomes virtually absent near the summit of the hill.

3. Methods and Procedures

Field study was conducted in late July to early August, 1991. A belt-transect 114 m long and 2 m wide was established from the base to the crest of the drumlin hill. It perpendicularly crossed a series of the vegetation belts. The transect was sectioned in every 2 m interval to divide it into 57 successive square quadrats. In each quadrat, total coverage of vegetation was assessed in percent and vegetation was described in species composition and their coverage. Coverage was assessed in Domin-Krajina species significance class (Table 2). For convenience, earth hummocks were categorized *a priori* into three types based on the degree of vegetation coverage as follows (Fig. 4):

Type A: Top portion is largely bare but with base portion covered by vegetation;

Type B: Covered by vegetation except the very top portion;

Type C: Completely covered with vegetation without any bare portion left.

Table 2. 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	Scattersd, 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

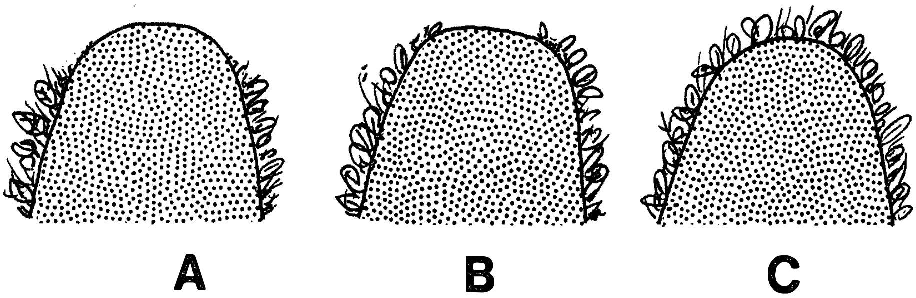

Fig. 4. Three types of earth hummocks designated according to degree of being covered with vegetation. Type A: those with top portion largely bare, Type B: those with small top portion devoid of vegetation, Type C: those completely covered by vegetation.

Their number in each quadrat was recorded. A topographical cross section of the hill along the belt-transect was surveyed with a transit theodolite by C. YOUNG. Soil temperature of an earth hummock was measured with a thermister thermometer at various points of the surface and inside of the hummock.

4. Results and Discussions

4.1. Nature of the earth hummock

Earth hummock was studied in some details. Figure 5 shows a cross section of a hummock. Substrate of the hummock was mostly aeolian fine sand and silt without any coarse fragments. Weak involution and distortion were faintly noted. Vegetation covering the hummock consisted mainly of *Salix arctica* mixed with *Dryas integrifolia, Polygonum viviparum, Poa abbreviata*, and *Pedicularis arctica.* Soil temperature of the hummock was measured (Table 3). Surface temperature ranged from 23.8 to 9.8°C with an average of 16.1°C. The highest temperature was naturally recorded on a south-facing position while the lowest on a north-facing side. This is presumably a reflection of the insolation effect. At the time

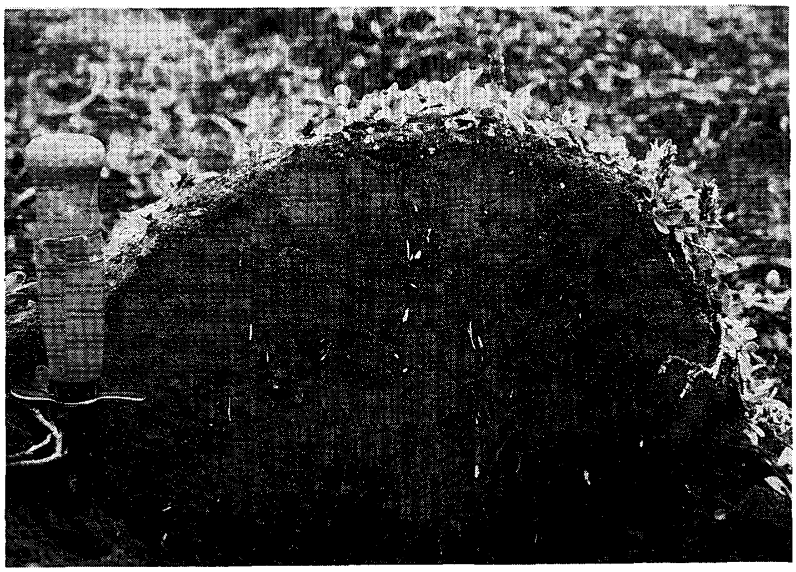

Fig. 5. A cross section of an earth hummock. Material consists of fine aeolian sand and silt.

Table 3. Soil temperature measurements (°C) of an earth hmock. The measurements were made on July 27, 1991, 1340 LT, under a clear sky.

Surface temperature			Inner center temperature	
Aspect	Shoulder	Base	Depth (cm)	Temperature
N	12.7	9.8	0	12.8
E	16.1	16.7	2	13.5
S	23.8	23.0	4	11.3
W	14.1	12.3	6	9.9
			8	7.8
			10	7.2
			12	6.7
			14	5.6

of the measurement, the sun was 18 degrees above the horizon due south under a clear sky. A strong unevenness of soil temperature was recorded inside the hummock. The lowest temperature was 5.6°C which was recorded in the bottom center of the hummock. Figure 6 illustrates temperature distribution interpolated from the measurements.

4.2. Vegetation and earth hummock development along the belt-transect

Table 4 shows the vegetation structure of the belt-transect and numbers of earth hummocks in the quadrats. A total of eighteen species of vascular plants were recorded in the transect. Of them, *Salix arctica* was most abundant, appearing in 50 of the 57 quadrats. *Dryas integrifolia* and *Saxifraga oppositifolia* were the second and third most abundant species, occurring in 39 and 30

Table 4. Vegetation structure of the belt-transect. Numerals following species represent cover value in Domin-Krajina's spedies significance class.

Section	I				II										III						IV					
Quadrat No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
Number of hummocks*					36	37	37	33	23	22	23	24	33	25	23	23	30	29	27	35	26	36	38	35	30	30
type A					36	30	31	28	19	17	18	19	26	16	5	4	3	1	1	3	12	0	1	0	0	0
type B					0	7	6	5	4	5	5	5	7	8	16	16	23	23	18	29	1	2	3	0	3	5
type C					0	0	0	0	0	0	0	0	0	1	2	3	4	5	8	3	13	34	34	35	27	25
Total vegetative cover**	I	II	II	II	II	II	II	II	II	II	II	II	III	III	III	III	IV	IV	IV	V	V	V	V	V	V	IV
Salix arctica	4	5	6	6	6	5	6	6	6	6	6	6	6	6	7	6	7	7	8	8	9	9	9	9	8	8
Poa glauca	3	2	2	3	2	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Potentilla vahliana	4	4	4	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Poa hartzii	+	1	.	+	.	+	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Poa abbreviata	.	.	.	.	.	+	+	+	+	+	+	1	+	.	+	+	+	.	.	+	+	.	.	.	.	.
Saxifraga oppositifolia	.	.	.	.	.	.	.	.	+	+	.	1	+	2	1	3	4	+	+	2	+	+	+	3	+	+
Dryas integrifolia	.	.	.	.	.	.	.	.	.	+	.	3	+	5	3	5	+	4	4	4	4	3	+	2	4	4
Alopecurus alpinus	.	.	.	.	.	.	.	.	.	.	+	.	.	+	+	.	.	+	.	.	.	.	.	.	.	.
Stellaria longipes	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	+	.	+	.	.	.	.
Pedicularis arctica	.	.	.	.	.	.	.	.	.	.	.	.	.	+	+	+	1	+	+	+	1	+	+	.	.	.
Polygonum viviparum	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.
Carex misandra	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	+	1	.	+	.	.	.	.	.
Carex nardina	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.
Lesquerella arctica	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Poa arctica	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Draba groenlandica	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Braya purpurascens	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Oxyria digyna	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.

Table 4. (Continued).

Section	V											VI												VII						VIII	
Quadrat No.	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	44	43	45	46	47	48	49	50	51	52	53	54	55	56	57
Number of hummocks*																															
type A																															
type B																															
type C																															
Total vegetative cover**	III	IV	IV	III	III	III	III	III	II	II	II	I	I	I	II	I	.	.	.	I	I	I	I	II	III	V	IV	III	I	I	.
Salix arctica	7	8	7	6	6	5	5	6	5	4	4	2	5	+	4	+	.	.	.	2	.	.	2	4	5	6	4	2	+	.	.
Poa glauca	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Potentilla vahliana	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.
Poa hartzii	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Poa abbreviata	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	+	.	.	.	+	.	.	+	+	.
Saxifraga oppositifolia	.	1	+	+	1	2	3	1	4	4	.	.	.	.	.	.	.	.	.	.	.	.	.	4	4	+	3	.	.	.	.
Dryas integrifolia	4	2	2	5	5	5	6	5	4	5	5	4	2	4	5	4	.	.	.	.	.	.	+	5	5	8	8	7	5	.	.
Alopecurus alpinus	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Stellaria longipes	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Pedicularis arctica	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Polygonum viviparum	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Carex misandra	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Carex nardina	+	+	.	.	+	+	+	+	2	1	2	+	2	1	1	2	.	.	.	+	.	+	.	+	.	3	.	+	.	+	.
Lesquerella arctica	.	.	.	+	.	.	.	.	+	.	.	+	.	.	.	.	.	.	.	.	.	.	.	+	+	.	.	.	+	+	.
Poa arctica	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.
Draba groenlandica	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.
Braya purpurascens	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	+	.	.	.	.	.		.
Oxyria digyna	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.		

* Earth hummocks are only present in present in Secitions II, III and IV.
**Total vegetative cover:<20%, II:20-40%, III:40-60%, IV:60-80%, V:>80%

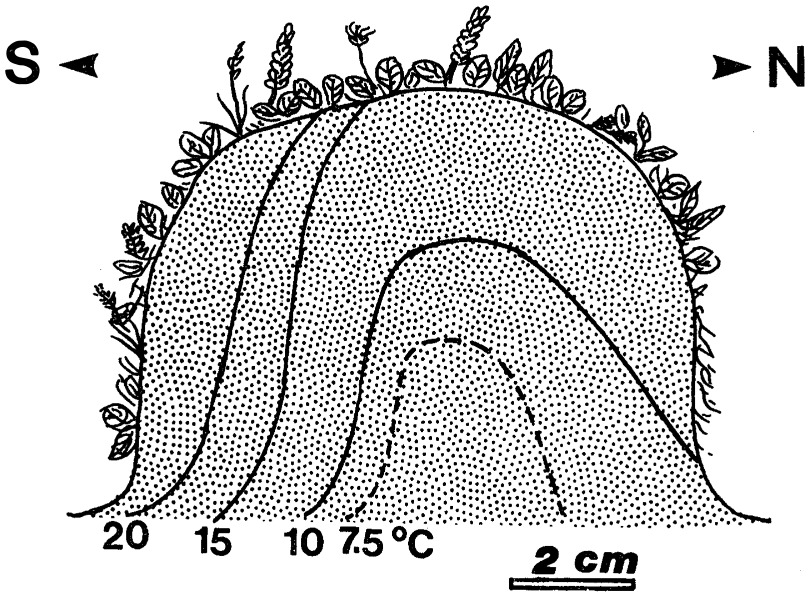

Fig. 6. Temperature distribution inside an earth hummock. The isotherms were interpolated from the actual temperature measurements. The measurement was made on July 27, 1991, 1340 LT under a clear sky, air temperature of 9.6°C.

quadrats, respectively. Other species in order of abundance were: *Carex nardina* (20), *Poa abbreviata* (18), *Pedicularis arctica* (10), *Lesquerella arctica* (7), *Poa glauca* (6), *Poa hartzii* (5), *Alopecurus alpinus* (4), *Potentilla vahliana* (4), and *Carex misandra* (4). Numerals in parentheses indicate number of quadrats. Other minor components appearing in less than four quadrats included: *Stellaria longipes, Poa arctica, Braya purpurascens, Polygonum viviparum, Draba groenlandica,* and *Oxyria digyna.*

The transect may be divided into eight sections (Sect. I–VIII) from base to top of the knoll based on vegetation characteristics and patterns of earth hummock development. Figure 7A shows a series of eight sections in relation to topographical profile of the transect. Table 5 shows an average of total vegetative cover and number of vascular plant species per quadrat for each section.

Section I was situated on a level topography at a slope base where vegetation weakly developed. The ground surface was covered with thin salt crusts, which indicated the saline condition of the habitat. In Sections II–IV near the base of the slope, abundant earth hummocks developed. The average number of earth hummocks in a quadrat was 29.8. Though the total number of earth hummocks did not differ much among sections, the type of earth hummock development differed considerably. In Section II, the majority of the earth hummocks was type A with large bare tops. Most such hummocks had many fractures at the top, which was an indication of degradation of the hummocks. There were practically no type C hummocks. In Section III, however, most of the hummocks were type B, *i.e.* covered largely by vegetation except very tops which were bare. In Section IV, most of the hummocks were type C. Such a shift of hummock types from A to C seemed to be related to the topographic

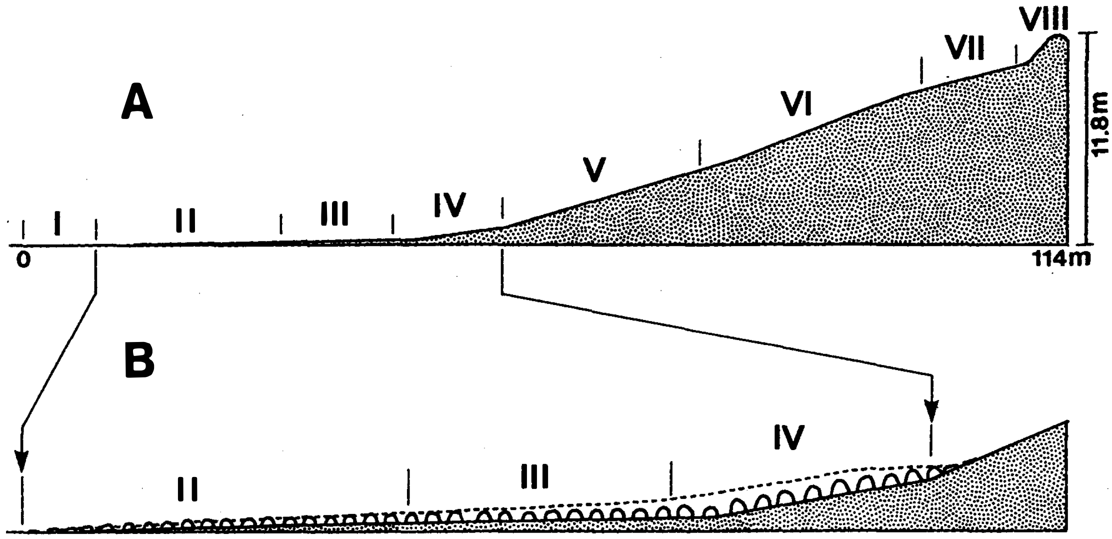

Fig. 7. A topographical profile of the belt-transect and positions of the eight vegetation sections. The upper profile (A) shows an entire transect. The vertical scale is twice the horizontal scale. The lower profile (B) is an enlargement of a portion of Sections II, III, and IV. The dotted line indicate a possible critical snow line to preserve the earth hummocks.

Table 5. Averages of total vegetative cover and number of species per quadrat for the sections.

Section	I	II	III	IV	V	VI	VII	VIII
Average of total vegetative cover (%)	25	34	67	87	45	9	50	5
Average number of vascular species / quadrat	3.8	3.5	5.8	4.2	4.4	2.3	4.2	1.5

position and subsequent pattern of snow accumulation. Vegetative cover became higher from Section II to IV where it reached almost 100% though species composition did not differ much among the three sections. Height of the earth hummocks generally increased from Section II to IV along with shift of the dominating hummock types from A to C. In fact, in Section II it ranged *ca.* 10–20 cm whereas it was 30–50 cm in Section IV. But it was remarkable that the hummocks abruptly degenerated and disappeared from Section IV to V within half a meter or so. Sections V and VI were situated on a relatively steep middle slope. No hummock developed there. Vegetative cover was reduced substantially. In general, *Carex nardina* exhibited a comparatively high constancy in both Sections V and VI. Vegetative cover became characteristically low in Section VI, and quadrats 43–35 were completely devoid of vascular vegetation. Section VII was situated on an upper slope near the summit of the knoll. Here the slope became gentle and vegetative cover increased again. *Salix arctica, Dryas integrifolia, Saxifraga oppositifolia, Carex nardina,* and *Lesquerella arctica* exhibited a relatively high constancy. The occurrence of the last species was characteristic to this section as it occurred in three quadrats out of six, which indicated that the soil is highly calcareous. Section VIII was situated right on the summit of the knoll. The relief was convex. Vegetative cover was extremely low and practically no vascular vegetation developed, particularly in quadrat 57.

4.3. Processes of earth hummock development and maintenance

For earth hummock development, the presence of permafrost and homogeneous fine soil material without coarse fragments seem to be prerequisite conditions, though the former may not necessarily be a mandatory condition as in Iceland they have developed in areas without permafrost (TROLL, 1944, cited in WASHBURN, 1956). Fine aeolian sand or silt deposits are a suitable material. Such a fine material should have likely been collected immediately after deglaciation. At that time, practically no vegetation had developed to protect ground surface from wind erosion. Alluvial deposits may also be a suitable substrate. ZOLTAI and TARNOCAI (1981) remarked that earth hummocks generally consisted of finegrained materials without vesicular structure. Soil needs to be moderately moist but not excessively.

Earth hummocks are initiated by polygonal cracking of the ground surface due to contraction of the solidly frozen ground when temperature becomes extremely low in winter. However, actual mound formation takes place in late fall or early winter. Internal pressure confined between permafrost and the freezing surface causes eventual upheaval of the center portion of the polygons to form a hummocky structure (CRAMPTON, 1977). The second stage is preservation of the mounds; at this stage snow plays a decisive role. Snow accumulation will protect the earth mounds from strong wind and erosion especially in winter. This is presumably why well developed earth hummocks are generally restricted to a leeward slope-base, where snow drifts and stays relatively long. The snow cover simultaneously encourages vegetation establishment on the earth hummocks by protecting it from mechanical abrasion and desiccation in winter due to strong wind with ice crystals (SAVILE, 1972). THURSTON and RAILLARD (1989) recognized that willow (*Salix arctica*) stands in the Sverdrup Pass area were covered by snow until mid-June. Snow cover is particularly beneficial to evergreen and semi-evergreen plants such as *Dryas integrifolia* and *Saxifraga oppositifolia.* Other plants such as *Salix arctica, Alopecurus alpinus,* and *Pedicularis arctica* will also be benefited from the snow cover. Snow would also provide an ample supply of water to plants. This is why the total vegetative cover as well as species richness becomes generally high in Sections II–IV, where earth hummocks develop well (see Table 5).

Thus, it may be considered that the three types of earth hummocks described earlier are indeed a manifestation of degree of snow cover. Portions of the hummocks which are exposed do not support vegetation development, thus are left naked. Type A hummocks are those with their top portions exposed from snow cover for most of the winter; type B hummocks are those with their tops barely covered by snow; and type C hummocks are those completely covered and protected by snow for the winter. Once vegetation is established on the earth hummocks, it in turn would protect and preserve the hummocks.

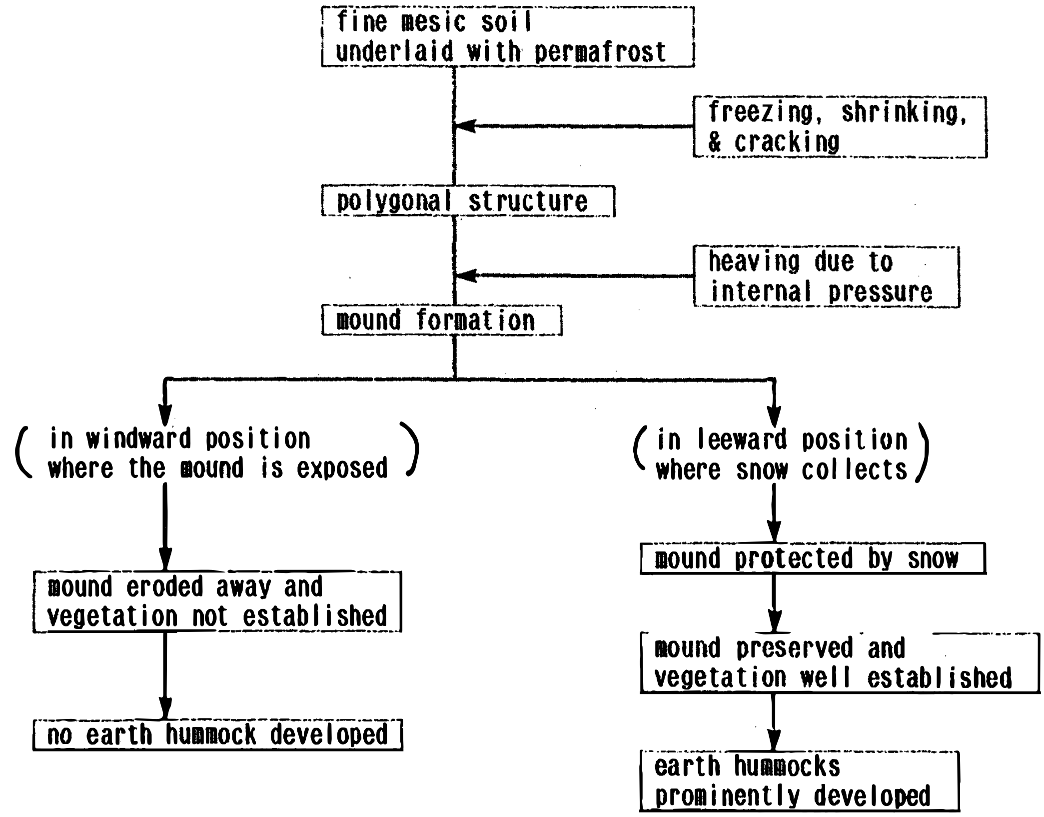

Fig. 8. A scheme showing earth hummock development processes.

Figure 7B illustrates a possible snow line critical to maintain vegetation, which was inferred from actual distribution pattern of the earth hummocks and vegetation characteristics.

It may be concluded that the well developed earth hummocks covered by dense vegetation, as observed at the study site, are indeed a product of synergistic interactions of topography, soil substrates, permafrost, snow cover, and vegetation. Figure 8 illustrates schematically such development processes of the earth hummocks. The present study site provided an excellent example of such interactions and development of earth hummocks.

5. Summary

Relationships of vegetation, earth hummocks, and topography were studied in the high arctic environment on Ellesmere Island, Canada. A 2 m × 114 m belt-transect was established on a southwest-facing slope of a small knoll of drumline origin, where well developed earth hummocks were recognized. It was segmented into 2 m × 2 m quadrats. In each quadrat, vegetation was described and the earth hummocks were counted and classified into three different types based on degree of vegetative cover. The transect was segmented into eight sections according to vegetation structure and the type of earth hummock development. Vegetative cover was very high where the earth hummocks de-

veloped well. The well developed earth hummocks were concentrated at the leeward slope base of the knoll, where possibly snow would have drifted and stayed long to protect vegetation and earth hummocks from winter blizzard conditions. It is considered that snow played a decisive role in preserving the earth hummocks and letting vegetation become well established. In conclusion, the well developed earth hummocks in the study site are regarded as a product of interactions of soil substrates, topography, snow, and vegetation.

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