Soil Temperatures in the Active Layer, Beaufort Plain

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ABSTRACT. This paper describes soil temperatures measured in the active layer on slopes of varying orientations in northwest Banks Island during the summer of 1968. High soil temperatures often in excess of 60°F. at a depth of 1 inch are not uncommon in areas underlain by Beaufort Formation and reflect the high thermal conductivity and low heat capacity of these materials. The relation between the microclimates of slopes of varying orientations and the asymmetrical nature of the valleys of the region is briefly discussed.

RÉSUMÉ. *Températures du mollisol dans la plaine de Beaufort.* Ce texte décrit les températures mesurées dans le mollisol, sur des pentes d'orientations diverses, dans le nord-ouest de l'île de Banks, au cours de l'été de 1968. Des températures élevées, souvent supérieures à 60°F (16°C) à une profondeur d'un pouce (25 mm) ne sont pas rares dans les aires sises sur la formation de Beaufort et reflètent la forte conductivité et la faible rétention thermiques de ces matériaux. On étudie brièvement la relation entre les micro-climats des pentes d'orientations diverses et la nature asymétrique des vallées de la région.

РЕЗЮМЕ. *Температура грунта активного слоя (Бофортская низменность).* Дается описание данных измерения температуры грунтов активного слоя, проведнного летом 1968 г. на склонах различной ориентации в северо-западной части о. Банкс. Значения температуры выше 60°F, отмеченные на глубине 1 дюйм в грунтах, подстилаемых формацией Бофорта, свидетельствуют о высокой теплопроводности и низких значениях теплоемкости этих пород. Дается краткое описание зависимости микроклимата на склонах различной ориентации от асимметричного расположения речных долин в исследуемом районе.

INTRODUCTION

Few soil temperature measurements have been made in the Canadian Arctic islands. Soil temperatures have been recorded at Resolute for a number of years in scattered localities (Cook 1956; Drew *et al.* 1958). In the western arctic islands, however, the only statement on soil temperatures has been made by Tedrow and Douglas (1964) working in an area of Central Banks Island (121°54′W., 73°23′N.). Tedrow and Douglas observed that soil temperatures in Beaufort materials were relatively high, compared with other similar arctic environments.

FIELDWORK

During the summer of 1968 fieldwork was carried out on the Beaufort Plain of northwest Banks Island to investigate the thermal properties of soils developed upon the Beaufort Formation. This paper is a preliminary account of the observations which were made, together with some conclusions as to their geomorphic implications.

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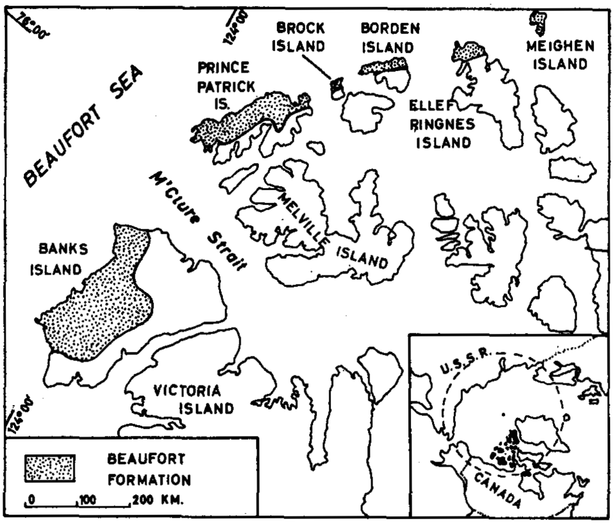

FIG. 1. Location map and distribution of Beaufort Formation in the Western Canadian arctic islands.

The Beaufort beds outcrop widely in the western Canadian Arctic (Fig. 1) and consist of unconsolidated sands and gravels together with shale units. On northwest Banks Island the formation reaches a thickness of over 200 feet (Hills 1969). It is probably late Tertiary and fluviatile in origin (Tozer and Thorsteinsson 1964). The Beaufort Plain consists of a gently undulating, fluvially dissected, plain which probably lay to the south and west of the limits of the last Wisconsin glacial advance through M'Clure Strait to the north (see Geological Survey of Canada

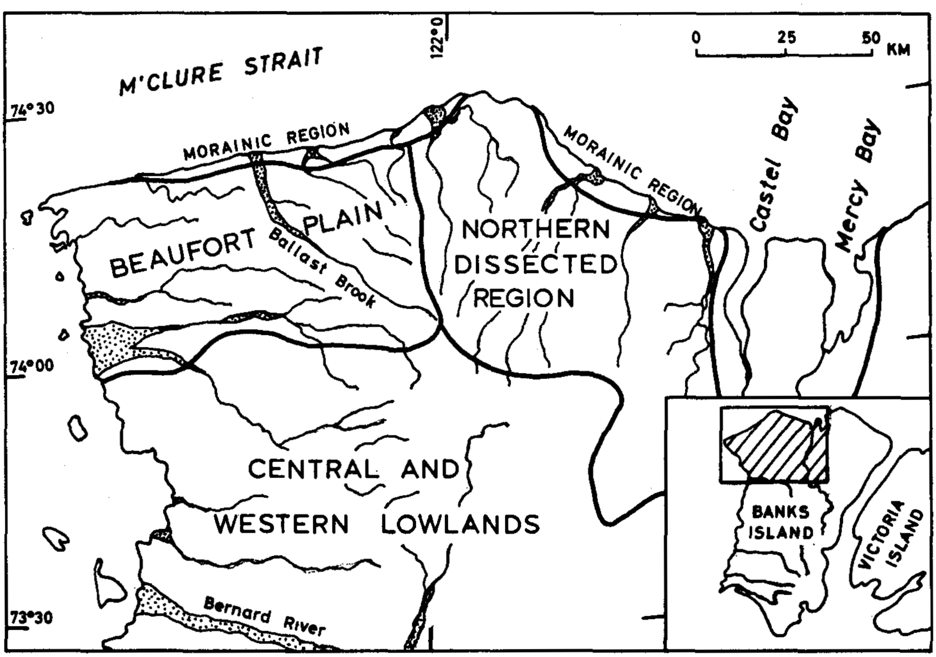

FIG. 2. Northwest Banks Island. Location of the Beaufort Plain and the major drainage lines.

1968). The plain is distinct from other adjacent areas underlain by the Beaufort Formation on account of the remarkable uniformity of its surface, the absence of lakes, and by the lack of any recognisable veneer of glacial sediments. Erratic boulders, however, occur scattered over the surface of the Plain and the geomorphic history of the area has not been satisfactorily outlined yet (Fyles 1962, p. 17). The action of running water in this area is overwhelmingly the dominant control in landscape evolution. The Beaufort Plain is currently being dissected by a series of valleys running approximately parallel to each other in a SE-NW direction (Fig. 2). To some extent, this pattern may be a reflection of the warping of the entire Beaufort Formation towards the northwest so that the beds became confluent with sea level at the edge of the Beaufort Sea. A striking characteristic of these valleys is that many are asymmetrical possessing steeper slopes oriented to the southwest.

FIG. 3. Asymmetrical valley, Northwest Banks Island, 8 miles SE of exit of Ballast Brook. Looking SE, August 1968. Photo: H. M. French.

Thermocouples were inserted, at depths of up to 25 inches at 4 sites in a small valley about 8 miles south of the exit of the Ballast Brook (see Fig. 3). The method of installation was by digging a pit to the permafrost table and then back-filling after the thermocouples had been pressed into the soil on the upslope side of the pit at the required depths. The 4 sites that were selected possessed SW, NE, NW and SE exposures. Soil textures were of a sandy to a gravelly sand loam and, provisionally, the soils were grouped into either the *Kellett* or *Bernard* series as recognised by Tedrow and Douglas (1964) in Central Banks. The angle of slope at each site was between 5 and 10 degrees and drainage conditions appeared to be uniformly good. Detailed soil temperatures were only taken on 3 occasions, but these were spread out through the summer and were periods of varying weather conditions. Exceptionally hot and sunny weather occurred on 16 and 17 July; 5 to 6 August was a period of precipitation; and 18 to 19 August represented average, cloudy and overcast conditions. Daily surface maximum and minimum temperatures were also recorded throughout the summer.

REGIONAL CLIMATE

The regional climate experienced on the Beaufort Plain of northwest Banks Island will have an important bearing upon the soil temperatures recorded. At present there is no climatological station located in the north of the island. The nearest climatological records are to be found at Mould Bay, on Prince Patrick Island, at 76°14′N., Isachsen on Ellef Ringnes Island at 78°47′N., and Sachs Harbour, on the southwest corner of Banks Island at 71°51′N. Mould Bay is probably the most representative of the conditions existing on northwest Banks Island.

TABLE 1. Summer precipitation and temperature records, Mould Bay, 1951-68. Source: Thompson 1967 — updated to 1968 from Department of Transport, Canada, Meteorological Branch, records.

TEMPERATURE	1951-60	1962	1963	1964	1965	1966	1967	1968
May	12.6°F.	8.4	13.7	10.0	11.8	18.0	14.2	11.5
June	32.3	37.2	31.8	29.9	28.0	32.7	28.8	33.5
July	39.2	41.4	40.8	31.9	37.5	38.9	35.2	42.8
August	35.2	35.6	32.5	37.6	35.4	35.6	32.8	36.3
PRECIPITATION								
May	0.27″	0.10	0.56	0.20	0.01	0.42	0.29	0.29
June	0.15	0.53	0.86	0.85	0.00	0.08	0.07	0.01
July	0.67	0.55	0.48	0.69	0.21	0.61	1.04	0.13
August	0.84	0.64	1.79	0.65	0.00	0.43	2.25	0.19

Mean summer temperature and moisture conditions for Mould Bay for 1951 to 1968 are given in Table 1. The 10-year average, 1951 to 1960, revealed a July average temperature of 39.2°F. and of August 35.2°F. The period of time in which temperatures rise above 32°F. is short, lasting from approximately mid-June to early September. Precipitation is small at all localities in the western Arctic and, in many respects, the region is an arid one (Table 2). Over 50 per cent of the precipitation occurs during the summer months, May to August, and falls either as rain or snow.

TABLE 2. Total precipitation and snowfall equivalent, for the 3 W. Arctic stations. (Source: Thompson 1967).

	Average 1951-60	Average May-August	% May-August
Mould Bay	3.34″ p.a.	1.93″	57.7%
Isachsen	3.92″ p.a.	2.07″	52.8%
Sachs Harbour	3.85″ p.a.	2.22″	57.4%

Of particular relevance to this study was the effect of wind in promoting evaporation from the ground, thus modifying, through latent heat loss, the temperature regime. In Table 3, wind data for the 3 western arctic stations are presented. At Mould Bay and Isachsen, north and northwest winds predominate for the major-

TABLE 3. Wind data, Western Canadian Arctic stations, 1951-60.
Source: Thompson 1967.

	Direction of prevailing wind		%	Average Speed	Yearly average speed
Mould Bay (1951-60)	May	NW	26	11.7 mph.	12.5 mph.
	June	NW	20	13.0 "	
	July	NW	25	12.2 "	
	August	NE, S	16	11.2 "	
Isachsen (1951-60)	May	N	25	1.0 "	9.5 mph.
	June	N	30	9.9 "	
	July	NW	23	10.9 "	
	August	N, SW	18	10.0 "	
Sachs Harbour (1951-60)	May	E	25	12.8 "	13.0 mph.
	June	N, E	20	12.8 "	
	July	NW	19	13.1 "	
	August	SE	23	13.6 "	

ity of the summer, with average speeds of over 10 m.p.h. At Sachs Harbour, too, the northwest winds are strong, especially in July.

Within this regional context, the climate experienced by northwest Banks Island is distinctive to some extent. This northwest corner of the island is directly exposed to northwest winds coming from the Beaufort Sea and is not protected to the same extent as either Mould Bay or Isachsen. Secondly, in late August, M'Clure Strait to the north opens up and there is a considerable stretch of open water for 2 months. Cold winds moving southwest pick up moisture and promote the development of dense fogs during the middle and late summer. A third local factor to consider is that northwest Banks Island presents few major topographic barriers to the inland movement and transport of maritime conditions. The highest land for much of the area is less than 500 feet and the plateau slopes gradually towards the west and northwest, thus allowing the unimpeded advance of maritime influences. In particular, several broad, flat, valleys often ½ to 1 mile in width, which open onto the north coast (e.g. Ballast Brook), offer easy access to the interior.

TABLE 4. Summer precipitation, Mould Bay, illustrating average amounts 1951-60 (Source: Thompson 1967) and actual amount, 1968 (Source: Canada, Meteorological Branch, records).

	Average (1951-60)	Amount 1968	% Deficit
	May-August	May-August	
Mould Bay 76° 14'N.	1.93″	0.62″	67.9%

The summer of 1968, however, cannot be regarded as a typical year in the western Canadian Arctic. Temperatures at Mould Bay for 1968 (Table 1) reveal that the July average of 42.8°F. was the warmest, probably, for the last 15 years. Also, June was exceptionally warm with mean temperature having been exceeded only in 1962. Snow melt on Banks Island during the early weeks of the summer was well advanced because of these unusually high temperatures.

Precipitation records from Mould Bay also indicate the abnormal climate of the 1968 summer in the western arctic. In 1968, only one third of the normal summer precipitation fell, as Table 4 illustrates. Since there is a close relationship between the records of all 3 western arctic stations it is probable that these abnormal conditions were widespread throughout the western arctic during the summer of 1968.

TABLE 5. Days in which minimum surface temperatures dropped below 32°F., N.W. Banks Island, Summer 1968.

	No. of Observation Days	Days below 32°F.	% Days below 32°F.	Average temp. fall below 32°
SW facing slope	40	25	63	2.68°
NE facing slope	40	11	27	2.05°
NW facing slope	36	16	61	4.75°
SE facing slope	34	7	20	1.40°

DAILY TEMPERATURE FLUCTUATIONS

Maximum and minimum surface temperatures were recorded at each locality at regular 24-hour intervals throughout the duration of the stay on the island. On no slope did the maximum daily surface temperature drop below 32°F. although, on many occasions, the minimum temperature did so. The number of days in which surface temperatures fell below 32°F. is listed in Table 5. Slopes with the most frequent freezing and thawing were the southwest- and northwest-facing slopes with, in both cases, over 60 per cent of the observation days experiencing surface temperatures of below 32°F. Of the two, the northwest-facing slope falls considerably below 32°F. This is probably the result of surface cooling brought about by the presence of strong northwest winds producing a very striking surface-temperature cooling on that slope.

The maximum surface-temperature variation observed was 31 degrees F. between the southeast- and northwest-facing slopes, at 1300 hours on 18 July. At depths of 3 inches these differences were much reduced, however, and the maximum difference recorded was 5.7 degrees on 18 August at midday, between southeast- and northeast-facing slopes.

DIURNAL TEMPERATURE REGIMES AND MAXIMUM SOIL TEMPERATURES

Observations were made at approximately 2-hour intervals at each of the sites commencing 1530 hours 17 July. The weather was exceptionally good during the period of observation with clear skies, light winds and no precipitation, thus allowing the full effects of incoming solar radiation to be realised. Such conditions had been developing over the previous 3 days and the temperatures recorded probably represent the maximum temperatures occurring that summer on Banks Island. The maximum temperature recorded at a depth of 1 inch was on the southeast-facing slope at midday, 17 July. The value of 67°F. exceeded the maximum temperature of 59°F. recorded by Tedrow and Douglas (1964) for central Banks Island. At that time, the other 3 slopes had temperatures of 60.3°F. (southwest-facing), 59.0°F. (northeast-facing), 58.0°F. (northwest-facing). The previous afternoon, temperatures in excess of 60°F. were also recorded at sites A, C and D (see Fig. 4) and nearly reached at site B (58.5°F.). The relative warmth of these soils, compared to other observations made in similar latitudes is interesting: It could reflect high thermal conductivity and low heat capacity characteristics of the Beaufort Formation which are, in many places, exceptionally well drained.

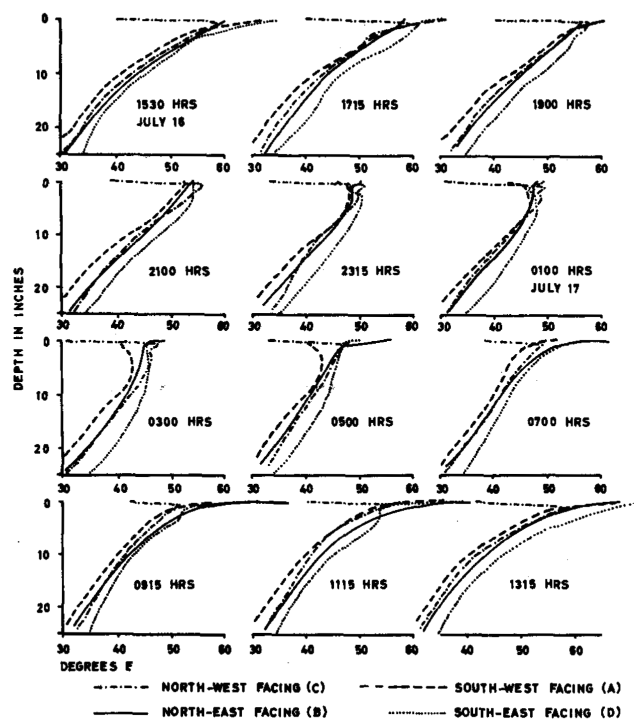

FIG. 4. Diurnal sequences of soil temperatures for 4 slopes, 16-17 July 1968.

The diurnal temperature regimes experienced by each of the 4 sites is illustrated in Fig. 4. The graphs show that, at depths of from 6 inches downward, the warmest of the 4 slopes was always that facing towards the southeast and the coldest was always that slope facing southwest. The active layer on the southeast-facing slope was the deepest, being in excess of 25 inches, whilst on all other slopes frozen conditions prevailed at depths of between 20 to 25 inches. This situation is clearly anomalous since it can be hypothesised that the two slopes facing towards the south would receive the greatest amounts of solar radiation whereas those facing towards the north would be the coldest. The absolute difference between the warmest (southeast-facing) and coldest (southwest-facing) slopes at depths of 12 inches varies from 3 to 5 degrees at most times. A maximum difference of 7 degrees occurred at 0300 hours. This might be taken to indicate that the coldest slope, the southwest-facing, can be related more to differences in heat loss through outgoing terrestrial radiation than to variations in heat gain through incoming solar radiation.

The changing position of the sun during the 24 hours of the arctic day has a predictable effect upon the near-surface temperatures of the slopes facing southeast, southwest and northeast. This can be well seen in Fig. 4. A striking feature, however, is the surface temperature of the northwest-facing slope. A marked surface inversion occurs throughout the observation period. This can be related most probably to the exposure of this slope to the dominant northwest winds which promote evaporation and subsequent heat loss from the surface of this slope.

THE EFFECTS OF SUMMER SNOWFALL UPON SOIL TEMPERATURES

Most of the annual precipitation of the western Canadian Arctic stations falls during the summer months of May to August, either as rainfall or snow (Table 2). The snow is particularly interesting in that it could modify the underlying temperature regime of the soil and also promote the mass-movement of soil.

Temperature observations were made during 5 and 6 August when a measurable summer snowfall occurred. Snow had been falling in flurries during the latter part of 5 August from an overcast sky of low cloud with a strong 15 m.p.h. northwest wind bringing moisture inland from the Beaufort Sea. At approximately midnight, the snow began to settle as the flurries became more continuous and by 0800 hours on 6 August, a 1-inch layer of snow covered the landscape. By 0900

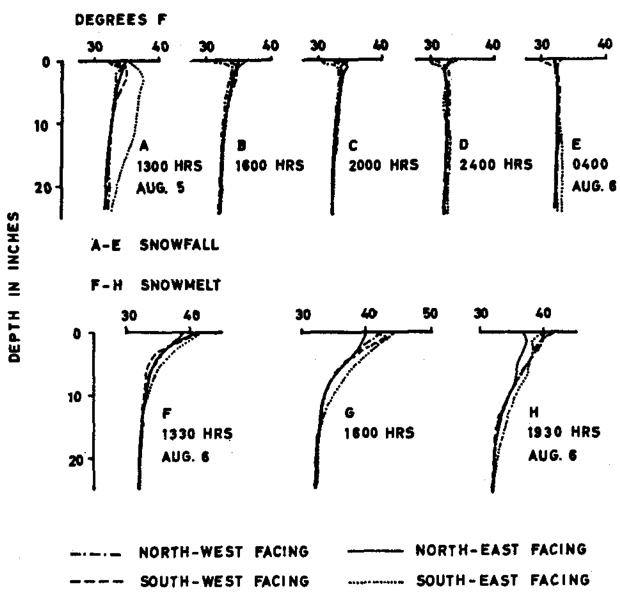

FIG. 5. Soil temperatures before, during, and after a period of summer snowfall, 5-6 August 1968.

hours, the snow ceased and at 1100 hours there was a break in the weather. The sun penetrated the clouds, surface temperatures began to rise and the snow began to melt. Within 2 hours, over 80 per cent of the snow had disappeared. Fig. 5 shows the temperature regimes of the 4 slopes measured at intervals over this period. It appears that the snow exerted an important influence upon soil temperatures, reducing them all to a near isothermal state, fluctuating just above the freezing point (Fig. 5, A to E). This change can be attributed to the rapid percolation of snow melt into the ground in the afternoon and early evening of 5 August, which would be greatly facilitated by the nature of the Beaufort materials. By midnight and early morning of 6 August, when snow blanketed the landscape, the temperature of the soil was isothermal for all sites, just above 32°F. with the surface temperature varying from 29°F. to 32°F. according to orientation.

Extremely rapid surface warming of the soil took place during the period of snow melt. By 1330 hours the surface temperature on all 4 slopes ranged from 38°F. to 42°F. reaching a maximum of 44°F. on the southeast-facing slope at mid-afternoon. By evening, 6 August, the normal diurnal drop in temperature had begun.

These temperature measurements show that very rapid thermal modifications are capable of taking place in the soils developed upon Beaufort materials. The ability of these soils to adjust so quickly to percolating water is indicative of their high degree of permeability, whereas the observations made subsequent to snow melt further confirm their low heat capacity and high thermal conductivity characteristics.

LATE SUMMER TEMPERATURES IN THE ACTIVE LAYER

Observations were made at the 4 localities on 18 and 19 August during a period of cool conditions with high cloud and occasional sunshine. Surface heating was not so great as in July and the patterns of temperature variations were not so clear

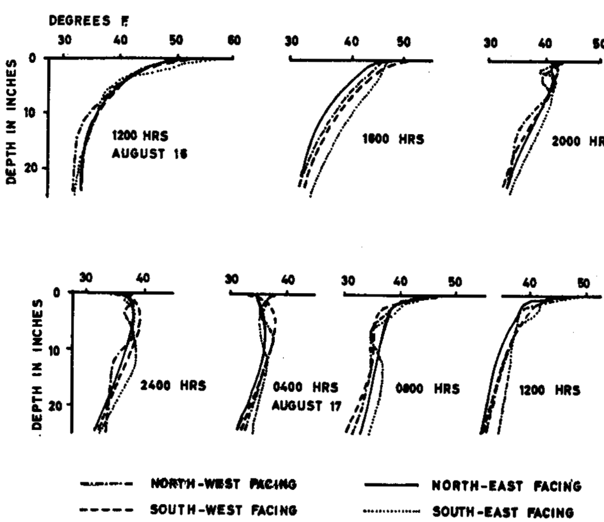

FIG. 6. Late summer temperatures in the active layer, 18-19 August 1968.

(Fig. 6). However, at depths of 12 inches and more, the southeast-facing slope is again the warmest on an average, whereas the other 3 localities portray temperature regimes which are relatively similar. There is a lack of a strong surface temperature inversion on the northwest-facing slope and this can be related to the absence of a strong northwest wind component on that day. Maximum soil temperatures at the 1-inch depth occurred on the southeast-facing slope at midday, with a value of 50.8°F. the other three locations being at temperatures near 45.0°F. As on previous occasions, the surface fluctuations followed a predictable pattern related to the movement of the sun around the horizon.

CONCLUSIONS

In general, it is clear that summer temperatures in soils developed upon the upper divisions of the Beaufort formation show high absolute values, compared with other analogous arctic regions. Temperatures at the 1-inch depth which are in excess of 60°F. are not uncommon. Thus, in sheltered valleys, the combination of high surface temperatures together with poor drainage and ground ice near the surface produce very favourable conditions for the growth of a relatively luxurious micro-flora in considerable quantities. The high maximum temperatures are thought to be a reflection of the nature of the Beaufort materials themselves. Observations indicate a very rapid adjustment of soil temperatures to prevailing environmental conditions such as direct solar radiation, summer snowfall or the presence of strong prevailing winds. The loose, sandy and gravelly character of the Beaufort materials promotes the rapid transmission of energy through the soil and also enables the quick downward penetration of both air and water.

The effects of orientation upon soil temperatures are best illustrated in the top 6 inches of the soil and follow a predictable diurnal pattern with respect to the angle and azimuth of the sun as it circles the horizon during the arctic day. Superimposed upon a general diurnal pattern of temperatures is a seasonal pattern related to exposure and to orientation. At depths of below 6 inches, the diurnal surface fluctuations are minimized and the southeast-facing slope appears to be the warmest slope for most of the summer, possessing an active layer in excess of 25 inches.

The effects of wind as an agent of landscape evolution seem to be important in this region and, probably, in periglacial regions in general. On northwest Banks Island some of the temperature variations are related to the strong northwest winds promoting evaporation and heat loss from exposed slopes. This has several geomorphological implications. For example, it is suggested that the southwest-facing slope is colder than the southeast-facing slope because the southwest-facing slope, being more exposed to the prevailing winds, loses more latent heat through the evaporation of soil moisture. For a similar reason the northeast-facing slope loses less heat and moisture than the northwest-facing slope. Thus, there is a strong microclimatic contrast between slopes facing northeast and those facing southwest. The northeast-facing slopes being moister and warmer promote the development of solifluidal processes to a greater extent than the drier, colder, southwest-facing slopes. Thus, an unequal amount of transported debris arrives at the basal channel, and the stream in response is pushed towards the southwest-facing slope to undercut and steepen it in angle. Thus, the asymmetry of the valleys of the Beaufort Plain appears to be closely related to the distinctive microclimatic conditions existing in this area, and is particularly influenced by the prevailing northwest winds which promote temperature variations on differently exposed slopes. The importance of wind as a geomorphological agent in the western Canadian Arctic has been stressed by Pissart (1966). Furthermore, Tedrow (1966) has observed that the wind is important in the formation of patterned ground features on the Polar Desert soils of Prince Patrick Island. The author believes that the observations described in this paper further emphasise the role of wind as a geomorphic agent influencing soil and landform development in this part of the Arctic.

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REFERENCES

COOK, F. A. 1956. Near surface soil temperature measurements at Resolute Bay, N.W.T., Canada. *Arctic,* 8: 237-49.

DREW, J. V. *et al.* 1958. Rate and depth of thaw in Arctic soils. *Transactions of the American Geophysical Union,* 39 (4): 697-701.

FYLES, J. G. 1962. Physiography. In: Banks, Victoria, and Stefansson islands, Arctic Archipelago. *Geological Survey of Canada Memoir* 330, pp. 8-17.

GEOLOGICAL SURVEY OF CANADA. 1968. *Glacial Map of Canada.* Department of Energy Mines and Resources, Ottawa. Map 1253.

HILLS, L. V. 1969. Beaufort Formation, Northwestern Banks Island, District of Franklin. In: Report of Activities, April to October, 1968, *Geological Survey of Canada, Paper* 69-1, Part A, pp. 204-07.

PISSART, A. 1966. Le rôle géomorphologique du vent dans la région du Mould Bay, Ile Prince Patrick, N.W.T., Canada. *Zeitschrift für Geomorphologie,* 10 (3): 226-36.

TEDROW, J. C. F. 1966. Polar Desert Soils. *Proceedings of the Soil Science Society of America,* 30: 381-87.

TEDROW, J. C. F. and L. A. DOUGLAS. 1964. Soil investigations on Banks Island. *Soil Science,* 98: 53-65.

THOMPSON, H. A. 1967. The climate of the Canadian Arctic. Ottawa: Dominion Bureau of Statistics, 32 pp.

TOZER, E. T. and R. THORSTEINSSON. 1964. Western Queen Elizabeth Islands, Arctic Archipelago. *Geological Survey of Canada Memoir* 332, 242 pp.