AGE OF CRYOTURBATED ORGANIC MATERIALS IN EARTH HUMMOCKS FROM THE CANADIAN ARCTIC

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Buried organic materials were collected from under 26 earth hummocks in the arctic and subarctic regions of Canada. Radiocarbon dates were obtained from 50 samples (peat, wood, and other organic material), both from the active layer and from the near-surface permafrost. Ages of the buried materials are not clearly related to depth of burial or to position under the hummocks. The burial was due to cryoturbation in most cases. Most materials are younger than 4,800 years. Cryoturbation is believed to have been intense during the early periods, beginning about 4,500 years ago simultaneously in all regions. Most hummocks were formed during the initial period between 4,500 and 2,500 years ago, but burial of surface material is continuing on a reduced scale to the present.

ÂGE DES MATÉRIAUX ORGANIQUES CRYOTURBÉS QUI COMPOSENT LES THUFURS DE L'ARCTIQUE CANADIEN

On a recueilli des matériaux organiques profonds, que recouvraient 26 thufurs dans les régions arctiques et subarctiques du Canada. On a effectué la datation au radiocarbone de 50 échantillons (tourbe, bois, et autres matériaux organiques), à la fois dans le mollisol et le pergélisol proches de la surface. On n'a pas pu établir clairement de corrélation entre l'âge des matériaux enfouis et la profondeur ou la situation de ces matériaux au-dessous des thufurs. Dans la plupart des cas, c'est la cryoturbation qui a provoqué l'enfouissement des matériaux, qui en général ont moins de 4 800 ans. On pense que les processus de cryoturbation ont été intenses pendant leur phase initiale, qui a débuté simultanément il y a environ 4 500 ans dans toutes les régions. La plupart des thufurs se sont formés pendant la période initiale qui se situe entre 4 500 et 2 500 ans, mais l'enfouissement des matériaux de surface se poursuit actuellement à une échelle réduite.

ВОЗРАСТ ОРГАНИЧЕСКИХ ОТЛОЖЕНИЙ В ЗЕМЛЯНЫХ КОЧКАХ В КАНАДСКОЙ АРКТИКЕ

В арктических и субарктических районах Канады из 26 земляных кочек были взяты образцы погребенных органических отложений. Была произведена датировка радиоуглеродным методом 50 образцов /торфа, древесных остатков и других органических отложений/, взятых как из активного слоя, так и из приповерхностных слоев многолетнемерзлого грунта. Возраст погребенных отложений не имеет четко-выраженной связи с глубиной погребения или их расположения под кочками. В большинстве случаев погребение было вызвано криотурбацией. Большая часть отложений имеет возраст менее 4800 лет. Можно предположить, что интенсивная криотурбация имела место в ранние периоды, начавшись примерно 4500 лет назад одновременно во всех районах
начальный период 4500-2500 лет наз
ложений продолжается и в настоящее

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INTRODUCTION

Earth hummocks are a type of nonsorted circle or net (Washburn 1973). They are hemispherical in shape, about 40-50 cm high and have a diameter of 1-2 m, but tend to be elongated along slopes (Zoltai and Tarnocai 1974). They invariably occur on fine-grained soils of clay to clay loam texture and can be found on permafrost terrain throughout the Subarctic and Arctic regions of Canada wherever the soil texture and moisture conditions are favorable for their formation. Earth hummocks were found on nonpermafrost terrain in the southern Mackenzie Valley, but were regarded as relict features on the basis of well-developed soil profiles (Zoltai and Tarnocai 1974). On permafrost areas they are almost always underlain by a layer of pure ice or high ice content material up to 1 m thick. Very frequently they contain buried organic material in amorphous or somewhat decomposed form.

Buried organic matter was noted in many soils in northern Alaska and Canada (Tedrow 1963, Tedrow and Douglas 1958, Hopkins and Sigafoos 1951, Mackay 1958). The organic material generally occurred a few centimetres below the top of permafrost either in continuous layers or in stringers. Organic material was also commonly found in the active layer in the form of continuous layers, intrusions, or involutions. The burial of the organic material has been attributed to cryoturbation (Hopkins and Sigafoos 1951), to gradual downhill movement of earth hummocks (Mackay 1958), or to decomposition during a warmer climatic period (Tedrow 1963).

The presence of incorporated organic matter offers a unique opportunity to study the effect of cryogenic processes on soil development and also to consider it in regional and zonal contexts. In the course of studies on terrain-vegetation-permafrost relationships in the Canadian Subarctic and

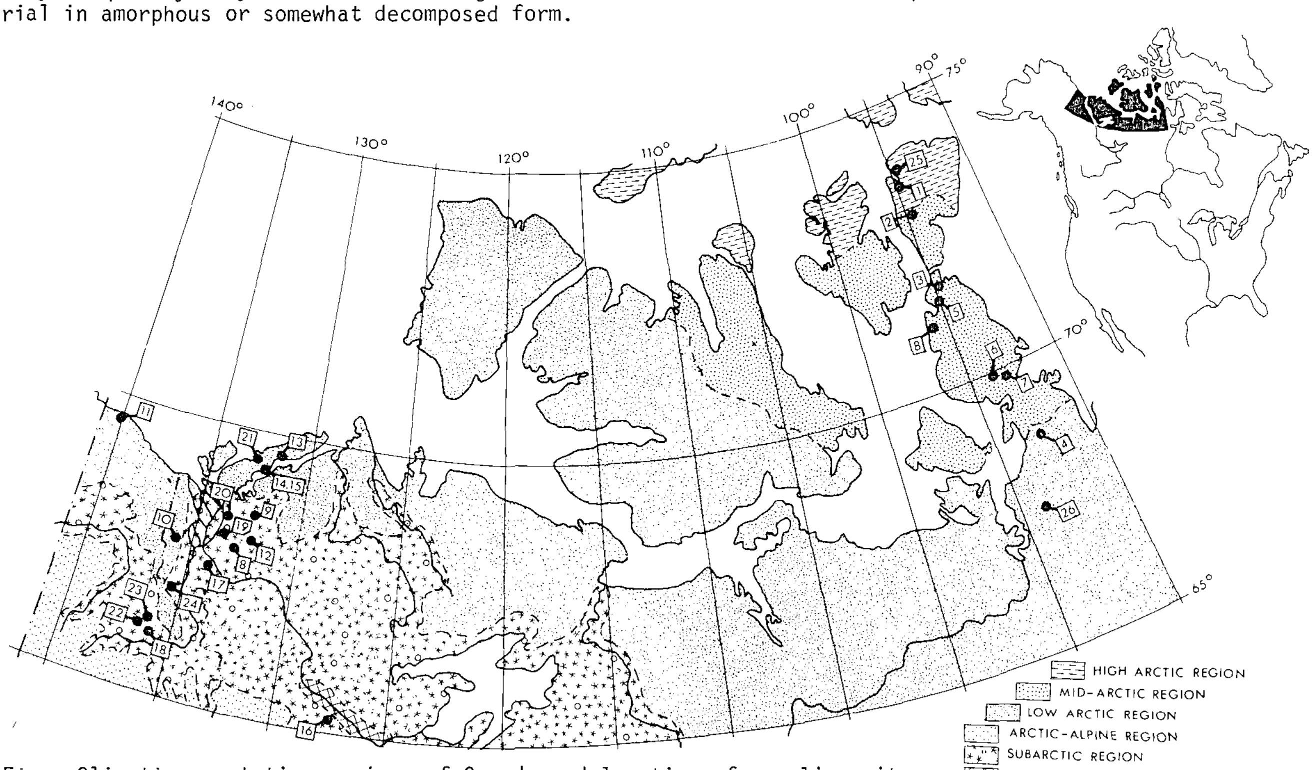

Fig. Climatic-vegetation regions of Canada and location of sampling sites. Vegetation Regions modified from The National Atlas of Canada (1973).

Arctic regions (Zoltai and Pettapiece 1973, Zoltai and Tarnocai 1974, Tarnocai 1973, Tarnocai et al. 1976) about 150 earth hummocks were excavated and examined in detail. Many of these contained buried organic materials in layers, involutions, smears, or pockets within the active layer or in the near-surface permafrost. Organic material was collected from 25 earth hummocks and 50 radiocarbon dates were determined.

The purpose of this paper is to examine the ages of cryoturbated organic material in the Subarctic and Arctic environments of northern Canada and to discuss their local and regional implications, with particular reference to soil stability and climate.

METHODS

In the western Arctic of Canada, earth hummocks were studied in the Low Arctic and Subarctic climatic-vegetation regions (Fig. 1). In the central Arctic most work was carried out in the Mid-Arctic region, but some hummocks were investigated in the High Arctic and Low Arcitc areas as well. In all cases well-formed hummocks were selected in areas where slope was less than 4%. Excavations were made at least 50 cm into the permafrost. The permafrost was distinguised from seasonal frost early in the season by the high ice content of the permafrost. The soil profiles were described and sampled, and the samples were later analyzed. The disposition of buried organic material was carefully noted in relation to the permafrost table and to hummock morphology.

The sampled organic material was immediately enclosed in an airtight container, often in a frozen state. The composition of the dated material was determined as peat, which is fibrous or slightly decomposed moss or litter; organic material, which is moderately to well decomposed, amorphous organic matter with high mineral soil content; or wood.

Most radiocarbon determinations were made by the Radiocarbon Laboratory of Brock University (BGS) and a few by the Geological Survey of Canada (GSC). In the laboratory the samples received standard treatment, including washing with distilled water, removal of organic acids with NaOH, and removal of carbonates with HCl, as required. The ages are uncorrected and are given as years B.P.

RESULTS

The radiocarbon dates (Table 1) range from 11200 to 500 years B.P., but most ages are younger than 5000 years B.P. The number of radiocarbon dates occurring during 500-year periods was plotted in bar diagrams (Fig. 2). In this analysis only two of the seven dates (BGS-204 and 209) obtained from Hummock 16 in the Subarctic region were used to avoid overrepresentation from this detailed site. The diagram (Fig. 2A) shows that the number of buried organic samples is fairly even from 5000 to 500 years B.P., with a peak in the 3000- to 3500-year range. The number of samples older than 5000 years, distributed from 5000 to 11500 years, is too low to show a pattern. The diagram of samples from different climatic-vegetation

Table 1. Radiocarbon dates from earth hummocks.

Sample no.	Location Lat. N	Location Long. W	Sample depth & position Centre (cm)	Sample depth & position Trough (cm)	Depth to permafr. (cm)	Sample from Permafr. or active layer	Material dated	Age (yr B.P.)	Lab. no.	Region
1a	73°37'	94°50'	55		68	A	Peat	3340±140	BGS-331	High Arctic
1b				35	20	P	Peat	525± 80	BGS-330	High Arctic
2a	72°58'	94°57'	72		53	P	Peat	3000± 90	BGS-335	Mid-Arctic
2b				53	15	P	Peat	2710±110	BGS-336	Mid-Arctic
3a	71°31'	94°10'	65		55	P	Peat	3140± 90	BGS-249	Mid-Arctic
3b			110		55	P	Peat	6420±100	BGS-248	Mid-Arctic
3c				42	32	P	Peat	4260± 90	BGS-250	Mid-Arctic
4a	68°30'	92°52'	62		54	P	Peat	2860± 90	BGS-246	Low Arctic
4b				34	30	P	Peat	1210± 80	BGS-247	Low Arctic
5	71°29'	94°52'	30		45	A	Org.	2440± 90	BGS-243	Mid-Arctic
6	69°57'	93°30'	59		50	P	Org.	4810±100	BGS-245	Mid-Arctic
7	69°48'	93°22'	80		63	P	Org.	3430± 80	BGS-244	Mid-Arctic
8a	71°03'	95°20'		31	44	A	Peat	2060± 80	BGS-242	Mid-Arctic
8b			31		35	A	Org.	1240± 90	BGS-241	Mid-Arctic
9a	68°27'	132°27'	110		80	P	Peat	2270± 80	BGS-190	Subarctic
9b				100	45	P	Peat	3980± 90	BGS-191	Subarctic

Table 1. (Continued)

10a	68°08'	135°49'		80	45	P		Peat	3850± 90	BGS-192	Low Arctic
10b			98		70	P		Org.	3770± 90	BGS-193	Low Arctic
11a	69°25'	139°59'		47	25	P		Peat	6240±110	BGS-194	Low Arctic
11b			52		50	P		Peat	5750±100	BGS-195	Low Arctic
12a	67°58'	132°43'	65		55	P		Org.	4280± 90	BGS-198	Subarctic
12b				45	27	P		Peat	3110± 90	BGS-199	Subarctic
13a	69°33'	131°35'		62	45	P		Org.	8160±110	BGS-200	Low Arctic
13b			62		55	P		Org.	8780±130	BGS-201	Low Arctic
14a	69°16'	132°20'		52	42	P		Peat	2400± 80	BGS-202	Low Arctic
14b			44		43	P		Peat	1210± 80	BGS-203	Low Arctic
15	69°16'	132°20'	90		65	P		Wood	4670± 90	BGS-213	Low Arctic
16a	65°10'	127°27'	49		84		A	Peat	2000± 80	BGS-204	Subarctic
16b			65		85		A	Peat	2060± 80	BGS-205	Subarctic
16c			65		80		A	Wood	1020± 80	BGS-206	Subarctic
16d			65		80		A	Peat	880± 80	BGS-207	Subarctic
16e				58	60		A	Wood	580± 80	BGS-208	Subarctic
16f				47	34		A	Wood	710± 85	BGS-209	Subarctic
16g				47	44	P		Peat	1100±100	BGS-210	Subarctic
17a	67°27'	133°50'		76	50	P		Peat	2780± 90	BGS-211	Subarctic
17b			54		70	P		Peat	3110± 90	BGS-212	Subarctic
18	66°05'	136°13'	50		90		A	Org.	1540± 70	BGS-150	Subarctic
19	68°08'	133°27'	85		75	P		Org.	4690±100	BGS-320	Subarctic
20	68°22'	133°45'	100		130		A	Org.	1660± 90	BGS-321	Subarctic
21a	69°26'	133°01'	70		60	P		Org.	5950±100	BGS-318	Low Arctic
21b				30	60		A	Org.	3030± 90	BGS-317	Low Arctic
22	66°10'	136°21'	105		65	P		Wood	500±180	GSC-2037	Subarctic
23a	66°05'	136°17'	20		50		A	Org.	3210± 50	GSC-1861	Subarctic
23b			55		50	P		Org.	3920± 50	GSC-2006	Subarctic
23c			62		50	P		Org.	11200±100	GSC-2018	Subarctic
24	66°50'	135°23'	85		70	P		Peat	1960± 60	GSC-1804	Subarctic
25a	73°46'	95°02'	82		55	P		Peat	9020±120	BGS-332	High Arctic
25b				67	32	P		Peat	9480±190	BGS-333	High Arctic
25c			99		55	P		Peat	8070±110	BGS-334	High Arctic
26	67°32'	94°03'		74	51	P		Peat	490± 80	BGS-403	Low Arctic

regions (Fig. 2B) also shows the peak in the 3000- to 3500-year range, with an equal peak in the Subarctic region in the 1500- to 2000-year range. Most dates in the Low Arctic region are in the 2000- to 4000-year range.

Most hummocks showed more than one layer or intrusion of buried organic material. In order to determine whether a **pattern** existed in the age distribution of these materials, two or more samples were taken for dating from many hummocks. The most detailed sampling was done from an earth hummock (No. 16) in the Subarctic region where seven age determinations were made (Fig. 3). The dates show that the material occurring within a few centimetres of the permafrost table, near the interhummock trough, is the youngest (16e and f). From here, moving downward (16g) and toward the center part of the hummock, the dates generally become older (16a and b). Young and old dates can occur together in the center part. Samples 16c and d have different ages, in spite of the fact that Sample 16c, a piece of wood, was enclosed in the peat of Sample 16d.

When ages of buried organic materials from under the interhummock trough and under the center of the hummock are compared, no definite pattern emerges. In some cases the material from the center is older than the material under the trough, but often the reverse is true. In 15 hummocks

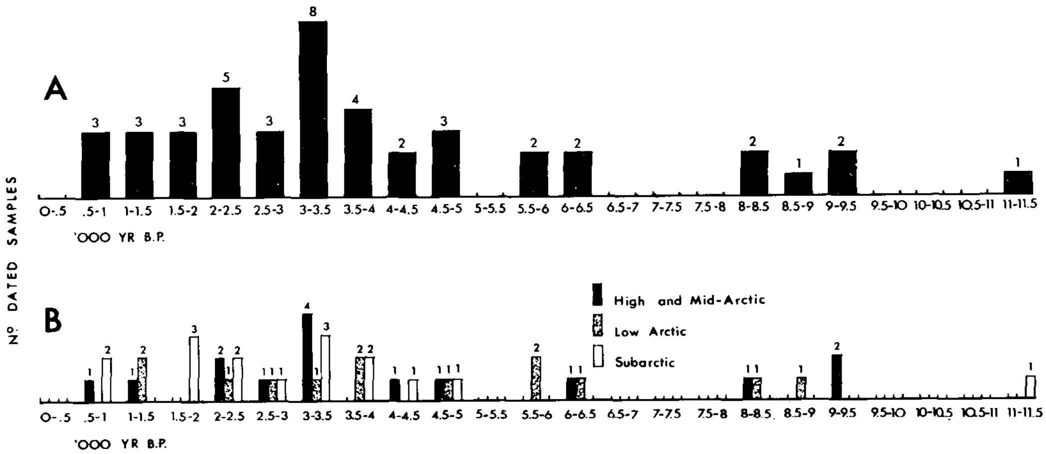

Fig. 2. A - Total number of dates in 500-year periods.
B - Number of dates by climatic-vegetation regions in 500-year periods.

where the age of the materials from the center and trough positions can be compared, 8 had older materials in the center and 7 under the trough.

Old and young materials can occur indiscriminately and, in two hummocks, were even found side by side. Hummock 23, located in an unglaciated part of the Yukon, yielded two dates in the 3000- to 4000-year range and a much older date only 7 cm deeper (Fig. 4). In another hummock (No. 3), the lower part of an apparently continuous layer gave a date far older than the upper part of the same layer.

DISCUSSION

Local Implications

The mechanism for the formation of earth hummocks is not known (Mackay and MacKay 1976). Because earth hummocks are associated with permafrost terrain (except for fossil forms), it is generally believed that pressures generated during the annual freezing of the active layer cause the materials to be displaced. Tree ring studies have shown (Zoltai 1975) that trees growing on hummocks are subject to periodic, sudden earth movements. Very frequently, soil horizons that should be near the surface are found buried by soil parent material, or horizons and horizon boundaries are disrupted by frost-churning (Tarnocai 1973, Zoltai and Tarnocai 1974, Pettapiece 1974, 1975). Similarly, buried organic material often appears in swirls of smeared streaks in the soil, suggesting movements in a viscous mass. This process is thought to be cryoturbation, a churning, mixing movement resulting in uneven displacement of soil materials in the active layer.

Cryoturbation mixes and blends the materials in the active layer; therefore, ages obtained from such material must be treated with caution. The juxtaposition of materials of different ages, as Samples 16c and d, illustrates this difficulty. Careful sampling may alleviate the problem but will not eliminate it. The analysis of several samples from the same earth hummock may further increase confidence in the ages obtained.

The origin of the buried organic material may be polygenetic, but cryoturbation appears to be the main mechanism for the burial. Organic material in the interhummock troughs may become buried by material heaved or extruded from the hummock. In some cases a hummock may move downslope by a slow roll-

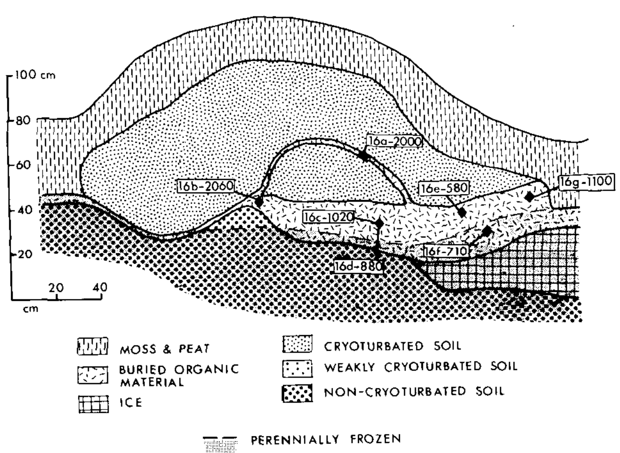

Fig. 3. Cross section of Hummock 16, with location of radiocarbon dated samples.

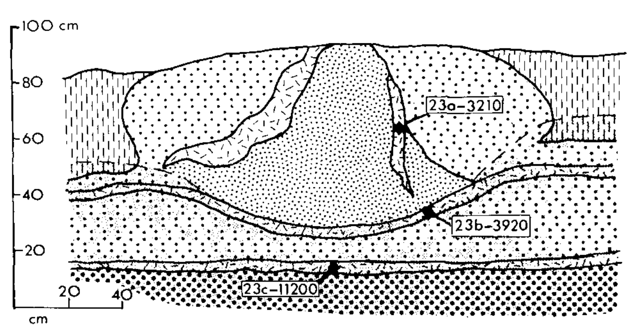

Fig. 4. Cross Section of Hummock 23, with location of radiocarbon dated samples. Legend as in Fig. 3.

ing motion which buries organic materials (Mackay 1958). Later extrusions or downhill movements will increase the thickness of soil over the buried organic material, increasing its relative position in the active layer, and raising the permafrost table in relation to the organic material. Eventually this process may result in placing the buried material within the permafrost, as shown by the deep burial of a relatively recent (500-year) material at Hummock 22 (Table 1).

A temporary increase in the thickness of the active layer may also account for the occurrence of buried organic materials in the permafrost. In the Subarctic areas forest fires cause a twofold increase in the thickness of the active layer, which may remain as long as 100 years after the fire (Pettapiece 1974). Although the ground is initially stable during the recovery stage, cryoturbation begins to be active some 70 years after the fire (Zoltai 1975). A change in climate to warmer conditions than at present may also result in a thicker active layer in all climatic regions, allowing a deeper burial of cryoturbated materials.

Some organic materials were buried by geological processes other than cryoturbation. The old date in Hummock 23 (11200 years) is probably from material buried under loess of an old, unglaciated surface. The dates at this hummock show that in the active layer materials can be moved by cryoturbation without disturbing the underlying old materials. Similarly, the materials in Hummock 25 are believed to have been deposited during a sedimentary process in a bay formed by the receding marine limit following the deglaciation of the area. The material, however, was shifted by cryoturbation, as shown by the younger age of the deeper material (Sample 25c: 8070 years) and the older age of the material overlying it (Sample 25a: 9020 years). The other old dates (e.g. Hummocks 3, 11, 13, and 21) probably resulted from the burial of old surface organic material or peat that accumulated on the surface before cryoturbation became active.

The occurrence of organic material several thousands of years old within the active layer illustrates the slow rate of decomposition in arctic and subarctic soils. At Hummock 23, material over 3ooo years old was found within 20 cm of the surface of this imperfectly drained soil. This material may have remained undecomposed for a few thousand years, but it is entirely possible that the material was moved close to the surface by cryoturbation during relatively recent times.

Some of the dates reflect the age of the hummocks, as well as the age of the cryoturbated materials, Hummock 15 occurred on a stablized surface of a thermokarst mudflow. Wood approximately 10 cm in diameter occurring in the underlying material at the 220-cm depth was dated at 5500±100 years (BGS-214), and woody peat from a cryoturbated organic layer beneath a hummock yielded a date of 4670 years (Hummock 15, Table 1). This shows that the slumped surface became stabilized and hummocks were formed in a space of about 1000 years.

Regional Implications

The radiocarbon dates (Table 1) indicate that most buried materials are less than 4800 years old. The age of the buried material, however, does not indicate the time of its burial, it gives only a minimum date of the burial. As the youngest buried material was dated at 490 years, one might assume that most surface materials were several hundred years old at the time of their burial. It is therefore estimated that the ages of buried materials dated at 4800 years and younger indicate the beginning of intense cryoturbation some 4500 years ago. This process continues to the present.

The preponderance of dates from the 3000- to 4000-year range (Fig 2A) suggests a severe rate of cryoturbation in the initial period. Had the rate of cryoturbation remained the same, one would expect to find more younger dates. It is possible that after the earth hummocks were formed some 2500-4500 years ago, as shown by the large number of samples in the 3000- to 5000-year range, they attained a state of equilibrium with the environment and became relatively stable. Studies of hummocks in the western Arctic and Subarctic of Canada noted that earth hummocks are relatively stable features (Mackay and Mackay 1976, Pettapiece 1975). Tree ring studies indicate an average of only one ground movement every 20 years during the last 200 years (Zoltai 1975).

Analysis of dates on an east-west gradient shows little difference in the ages of cryoturbated organic matter. The average age of 14 determinations (excluding ages over 5000 years) in the eastern part of the study area is 2537 years, while the average age of 21 samples in the western Arctic is 2796 years. Similarly, there is only a small difference in ages on a north-south gradient, arranged within present climatic-vegetation regions. The average age in the Mid- and High Arctic regions is 2814 years (11 samples), in the Low Arctic region 2610 years (9 samples), and in the Subarctic region 2562 years (15 samples).

Materials older than 5000 years recovered from the Low and Mid-Arctic regions were probably preserved in a permafrost environment. The lack of old materials from the glaciated Subarctic region suggests that permafrost was absent from the soils before 4500 years ago, or if present, it was associated with deep active layers where cryoturbation did not occur.

The onset of intense cryoturbation on previously stable surfaces throughout the Canadian north about 4500 years ago can be interpreted as a result of a climatic change. Cryoturbation is associated with high soil moisture levels and low temperatures. It is possible that the climatic change was toward colder and moister conditions. This assessment is supported by pollen studies in northern Canada where a cooling of the climate, beginning at 4800 years ago, is indicated (Nichols 1975). Studies of peat deposits in the Mackenzie

Valley (Zoltai and Tarnocai 1975) indicated that peat in the Subarctic region was deposited in a permafrost-free environment and permafrost began to develop in them about 4000 years ago.

CONCLUSIONS

1. Cryoturbation buries organic matter within the active layer. Some of this material may become part of the permafrost as cryoturbation causes it to be buried deeply.

2. No clear-cut pattern exists in the position of cryoturbated organic material: the deepest is not necessarily the oldest, and material at the edge of hummocks is not necessarily the youngest.

3. Some material was buried by sedimentary or aeolian process, but was also subject to cryoturbation.

4. Cryoturbation became active throughout northern Canada about 4500 years ago.

5. Climatic conditions became more severe in northern Canada some 4500 years ago. Permafrost conditions may have persisted in the Arctic areas before this time, but were probably absent from the present-day Subarctic areas.

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ТРУДЫ

ТРЕТЬЕЙ МЕЖДУНАРОДНОЙ КОНФЕРЕНЦИИ ПО МЕРЗЛОТОВДЕНИЮ

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ТОМ 1

ОРГАНИЗОВАННОЙ ПО ИНИЦИАТИВЕ
НАЦИОНАЛЬНОГО ИССЛЕДОВАТЕЛЬСКОГО СОВЕТА КАНАДЫ

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