Géographie physique et Quaternaire

A middle Pleistocene paleosol sequence from Dawson Range, Central Yukon Territory

Séquence de paléosols du Pléistocène moyen dans le Dawson Range, au centre du Yukon

Eine Folge von Paläoböden aus dem mittleren Holozän von der Dawson Range, Zentrum des Yukon-Gebiets

Lionel E. Jackson, Jr., Charles Tarnocai and Robert J. Mott

Volume 53, Number 3, 1999

URI: https://id.erudit.org/iderudit/004837ar
DOI: https://doi.org/10.7202/004837ar

See table of contents

Publisher(s)

Les Presses de l'Université de Montréal

ISSN

0705-7199 (print)
1492-143X (digital)

Explore this journal

Cite this article

Jackson, L. E., Tarnocai, C. & Mott, R. J. (1999). A middle Pleistocene paleosol sequence from Dawson Range, Central Yukon Territory. *Géographie physique et Quaternaire*, *53*(3), 313–322. https://doi.org/10.7202/004837ar

Article abstract

Four paleosols were intersected in a core drilled into the colluvial fill of a largely buried meltwater channel that was last active during the youngest of the pre-Reid glaciation (0.99-0.78 Ma) in the Dawson Range, Yukon Territory. The paleosols are classified as Podzols. The sedimentary sequence and paleosols indicate that at least two middle Pleistocene glacial and interglacial periods are represented in the core. The mean annual temperature exceeded 0° C for thousands of years in the upland environment of the Dawson Range at 61° N during these interglacial periods.

Géographie physique et Quaternaire, 1999, vol. 53, n° 3, p. 313-322, 3 fig., 4 tabl.

A MIDDLE PLEISTOCENE PALEOSOL SEQUENCE FROM DAWSON RANGE, CENTRAL YUKON TERRITORY*

Lionel E. JACKSON, Jr.**, Charles TARNOCAI and Robert J. MOTT, respectively: Geological Survey of Canada, Terrain Sciences Division, Suite 101, 605 Robson Street, Vancouver, British Columbia V6B 5J3; Agriculture and Agri-Food Canada Branch, 960 Carling Avenue, Ottawa, Ontario K1A 0C5 and Geological Survey of Canada, Terrain Sciences Division, 601 Booth Street, Ottawa, Ontario K18 0E8.

ABSTRACT Four paleosols were intersected in a core drilled into the colluvial fill of a largely buried meltwater channel that was last active during the youngest of the pre-Reid glaciation (0.99-0.78 Ma) in the Dawson Range, Yukon Territory. The paleosols are classified as Podzols. The sedimentary sequence and paleosols indicate that at least two middle Pleistocene glacial and interglacial periods are represented in the core. The mean annual temperature exceeded 0 °C for thousands of years in the upland environment of the Dawson Range at 61° N during these interglacial periods.

RÉSUMÉ *Séquence de paléosols du Pléistocène moyen dans le Dawson Range, au centre du Yukon.* Quatre paléosols ont été retrouvés dans une carotte lors d'un forage dans des colluvions de remplissage d'un chenal d'eau de fonte, en grande partie enfoui. Le chenal était en activité au moment de la plus récente glaciation du pré-Reid dans le Dawson Range. Les paléosols sont classés parmi les podzols. La séquence sédimentaire et les paléosols témoignent d'au moins deux périodes glaciaires et interglaciaires datant du milieu du Pléistocène. À 61° N, en moyenne montagne, les températures annuelles ont été supérieures à 0 °C pendant des milliers d'années au cours des périodes interglaciaires.

ZUSAMMENFASSUNG *Eine Folge von Paläoböden aus dem mittleren Holozän von der Dawson Range, Zentrum des Yukon-Gebiets.* Bei einer Bohrung in die Ablagerungsauffüllung eines zum großen Teil eingegrabenen Schmelzwasserkanals hat man vier Paläoböden gefunden. Der Kanal war zuletzt während der jüngsten Prä-Reid-Vereisung (0.99 - 0.78 Ma) in der Dawson Range, Yukon, aktiv. Die Paläoböden werden als Podsol klassifiziert. Die Sedimentabfolge und die Paläoböden lassen erkennen, dass mindestens zwei glaziale und interglaziale Perioden des mittleren Pleistozäns in dem Bohrkern repräsentiert sind. In diesen interglazialen Perioden betrug die durchschnittliche Jahrestemperatur in der Hochland-Umwelt von Dawson Range bei 61° nördlicher Breite über 0 °C während Tausenden von Jahren.

Manuscrit reçu le 6 juillet 1998 ; manuscrit révisé accepté le 12 mars 1999

* Geological Survey of Canada Contribution no. 1999011

** E-mail address: ljackson@gsc.nrcan.gc.ca

INTRODUCTION

Central Yukon contains a cumulative stratigraphic record of glaciations and interglaciations extending back to the Pliocene (Hughes *et al.*, 1989; Jackson *et al.*, 1996; Froese *et al.,* 1997; Jackson, in press). In this record, glaciations are documented by tills and allied glaciogenic sediments and interglacial intervals are interpreted from interstratified or geomorphically linked paleosols or nonglacial sediments (Table I). Smith *et al.* (1986) identified three widely distributed soils in central Yukon. The youngest, called the Stewart neosol, formed during the Holocene. The Diversion Creek soil is a paleosol formed prior to the last (McConnell) glaciation on deposits of the penultimate Reid Glaciation. The oldest soils, which date from the early or middle Pleistocene, are collectively referred to as the Wounded Moose soil. This paleosol usually occurs at or near the surface. Consequently, it has usually been truncated by erosion and quite likely has been repeatedly affected by pedogenesis during subsequent interglacial periods and it has been strongly cryoturbated during subsequent glaciations when it lay beyond the margins of Cordilleran glaciers (Foscolos *et al.,* 1977; Tarnocai *et al.,* 1985; Smith *et al*., 1986; Tarnocai 1987; Tarnocai and Smith, 1989).

In 1988, while exploring for gold, Archer-Cathro and Associates (1981) Ltd. inadvertently drilled through a sediment-filled former meltwater channel at an elevation of approximately 1250 m on a divide above the headwaters of Pony Creek, in the Dawson Range (62° 3’0" N, 137° 7’37" N). Core DDH-115, called the Pony Creek Core for the balance of the paper, was recovered from this operation. It was found to contain a succession of paleosols. The continuous 76 mm diameter core was drilled at an angle of 45° to the vertical. It was recovered downwards from 8.75 m below the surface. The meltwater channel was last active during the youngest of the early Pleistocene pre-Reid glaciations, between 0.99 and 0.78 Ma (Jackson *et al.*, 1996). Unlike most other middle or early Pleistocene paleosols described in Yukon, those encountered in the core were buried largely intact. Thus, their properties reflect soil formation and environments during single interglacial periods. Furthermore, the alpine setting of these paleosols contrasts with those of other paleosols studied in central Yukon which are predominantly located on the floors of major valleys.

TABLE I

*Generalized glacial and non glacial stratigraphy in the Dawson Range area**

Age	Glaciation	Interglacial soils and tephra
HOLOCENE		Stewart soil
PLEISTOCENE		
	McConnell Glaciation	
		Diversion Creek soil; Old Crow Tephra (*ca* 140 ka); Sheep Creek tephra (*ca* 190 ka)
	Reid Glaciation	
		Wounded Moose and Pony Creek soils
	---------------------------- 780 ka ---------------------	
	Youngest pre-Reid glaciation	
	---------------------------- 1 Ma ---------------------	
		Fort Selkirk tephra
	Older pre-Reid Glaciation	
PLIOCENE		

*(after Bostock, 1966; Jackson *et al.*, 1991; Jackson *et al.*,1996; Jackson, in press; Westgate,1989)

This paper details the analysis of these soils (called the Pony Creek soils) and core DDH-115 (Pony Creek Core) and their paleoenvironmental implications.

PHYSIOGRAPHIC SETTING

Pony Creek is located along the southeastern margin of the Dawson Range (Fig. 1; Jackson, 1997a). The Dawson Range is a part of, but rises above, Yukon Plateaus (Mathews, 1986), a rolling upland with broad and generally accordant summits and ridges that typically lie below 1500 m. Peaks in the Dawson Range rise up to 1820 m. Maximum local relief is on the order of 750 to 900 m from summits to the bottoms of adjacent trunk valleys.

Central Yukon has a sub-Arctic continental climate with long, bitterly cold winters, short mild summers, low relative humidity, and low to moderate precipitation (Table II). Intrusions of mild air from the Pacific Ocean moderate the climate of the region from the Arctic climate that characterizes northern Yukon (Wahl and Goos, 1987). The Dawson Range shares this climate modified by higher elevations. However, higher elevations do not necessarily experience colder temperatures throughout the year. Air temperature decreases with increasing elevation during the summer months but, during the winter, cold air is frequently trapped within the Yukon River Valley and other major valleys causing a temperature inversion (Wahl *et al.*, 1987). The Dawson Range has a periglacial climate. It is situated within a region of Yukon classified as having extensive discontinuous permafrost (Heginbottom *et al.,* 1995). However, the summits of the Dawson Range lie below the regional firn line.

QUATERNARY CONTEXT

Bostock (1966) recognized evidence of four glaciations in central Yukon. From youngest to oldest, he named these McConnell(Late Wisconsinan), Reid, Klaza, and Nansen. Because of the difficulty in distinguishing deposits of the Nansen and Klaza glaciations, Jackson *et al.* (1996) used the informal terms “younger” and “older” pre-Reid to name deposits of the two early Pleistocene glaciations they recognized in the Dawson Range area. The Pony Creek area has been ice-free since the last(younger) pre-Reid glaciation which is bracketed between 0.99 and 0.78 Ma (Jackson *et al.*, 1996). At that time, glaciers, originating more than 100 km to the southeast, in higher parts of the Cordillera (Hughes *et al.,* 1969), flowed up the Victoria Creek basin to at least the elevation of the Pony Creek drill site (Jackson, in

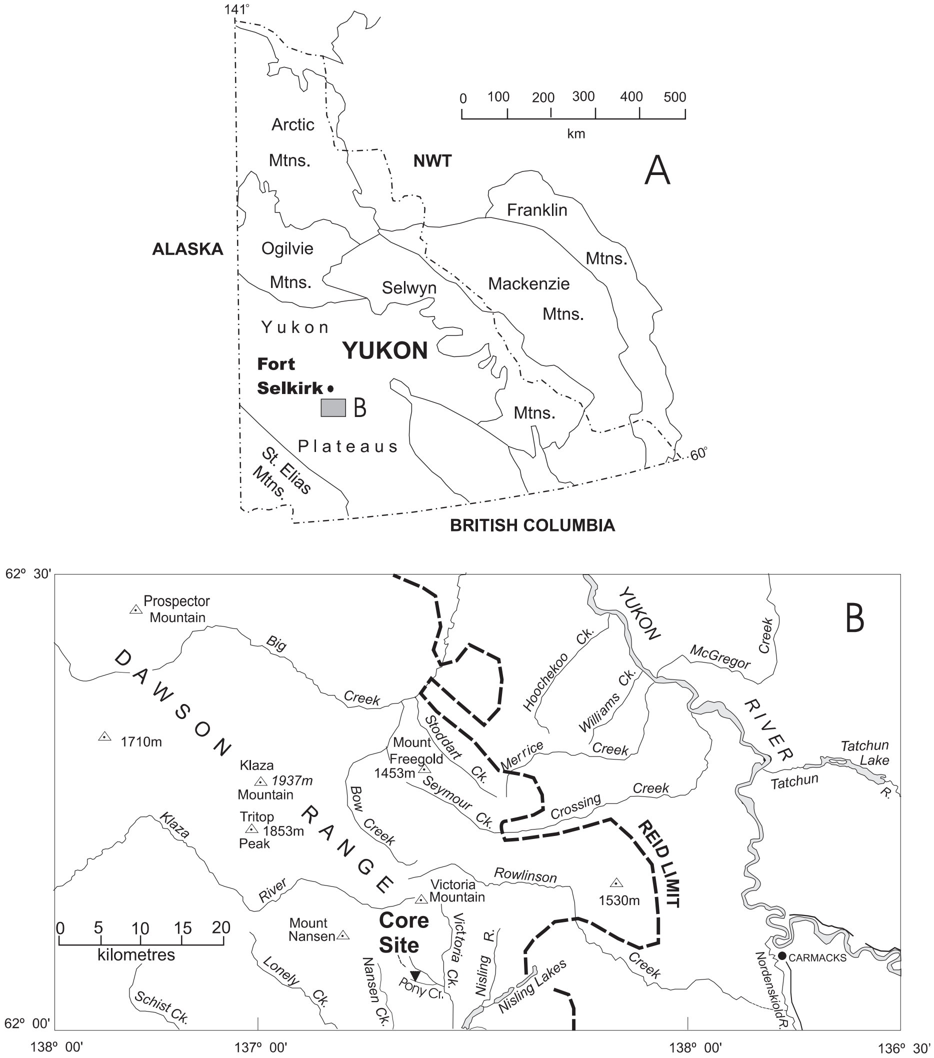

FIGURE 1. A. General map of Yukon and western Northwest Territories. B. Location of Dawson Range, west-central Yukon (physiographic provinces after Mathews 1986) and location of Pony Creek drill site. “Reid Limit” marks the limit of the Cordilleran Ice Sheet during the penultimate Reid Glaciation.

A. Carte généralisée du Yukon et de l’ouest des Territoires du Nord-Ouest. B. Localisation du Dawson Range, au centre-ouest du Yukon (provinces physiographiques de Mathews, 1986) et emplacement du forage de Pony Creek. Les « limites de Reid » représentent la limite de l’Inlandsis de la Cordillère pendant l’avant-dernière glaciation de Reid.

TABLE II

Climatic data for the Carmacks weather station, Yukon Territory, 1951-1980

Carmacks 62°6’N 136° 18’ W Elevation 523 m	January	July	Annual
Daily mean temperature	-28.2	14.5	-3.8
Extreme maximum (°C)	6.0	35.0	35.0
Extreme minimum (°C)	-57.8	-1.1	-57.9
Mean precipitation (mm)	18.4 (snow)	42.3 (rain)	254.3 (rain + snow)

press). Meltwater flowing along a glacier margin cut a channel across the drainage divide above Pony Creek. Paleosol-bearing fill then accumulated in this meltwater channel. Advances of Cordilleran glaciers during the subsequent Reid and McConnell glaciations reached no closer than about 15 km from the Pony Creek drill site (Hughes, 1990; Jackson, 1997a and b; Jackson, in press).

The site is close to the treeline with scattered stands of white spruce (*Picea glauca)*, aspen poplar (*Populus tremuloides)* and thickets of dwarf birch (*Betula glandulosa*). These give way with elevation to reindeer moss (*Cladonia* spp.). Soils are predominantly Regosols on slopes, but Brunisols occur on level sites. The Brunisols are comparable to the Diversion Creek soil, which developed during the last (Sangamonian) interglacial period *ca* 115-128 ka BP (Smith *et al.*, 1986). The Diversion Creek soils are up to twice as thick as the Holocene Stewart neosol which has formed widely and principally on deposits of the McConnell Glaciation in central Yukon. The Diversion Creek soil has B horizon colours that are the same as, or slightly more intense, than those of the Stewart neosol. It also commonly has Bt horizons with thin clay skins on ped surfaces (Tarnocai, 1987).

ANALYSIS OF THE PONY CREEK CORE

PEDOLOGICAL ANALYSIS

The paleosols and other sediments within the core were described and sampled at the drill site. The description and

TABLE III

Physical and chemical properties of paleosol horizons

Horizon	Vertical depth (m)	Vertical horizon thickness (cm)	Munsell Colour	Texture	$CaCO_3$	pH	C (%)	Sand (%)	Silt (%)	Clay (%)	Ammonium oxalate extractable (%) Sodium pyrophosphate extractable (%)		
											Fe	Al	Fe+Al
						Paleosol 1							
Ah	11.55-11.76	21	10YR 7/3	SL	1.13	6.1	1.07	56.4	36.2	7.3	0.70 0.28	0.11 0.02	0.81 0.30
Bf1	11.76-11.90	14	7.5YR 5/6	SL	0.91	6.4	0.52	55.5	38.9	5.5	1.31 0.14	0.11 0.01	1.42 0.15
Bf2	11.90-12.02	12	10YR 6/6	SL	1.02	6.3	0.7	54.6	40	4.6	1.00 0.12	0.11 0.01	1.11 0.13
						Paleosol 2							
2Ah	12.02-12.69	67	10YR 5/2	SL	2.05	6.3	0.81	51.6	45.7	2.6	0.19 0.04	0.10 0.01	0.29 0.05
2Bf1	12.69-13.06	37	7.5YR 5/6	SL	1.21	6.3	0.53	66.6	30.7	2.6	1.13 0.21	0.08 0.01	1.21 0.22
2Bf2	13.06-13.22	16	10YR 6/6	SL	0.78	6.5	0.29	64.1	31	4.8	1.12 0.16	0.09 0.01	1.21 0.17
						Paleosol 3							
3A	13.22-13.35	13	10YR 6/2	SL	0.95	6.3	0.56	60.6	35.3	4.1	0.50 0.07	0.08 0.01	0.58 0.08
3AB	13.35-13.46	11	10YR 6/6	SL	0.37	6.8	0.25	57.6	34.6	7.7	0.73 0.12	0.08 0.01	0.81 0.13
3Bf1	13.46-13.49	3	7.5YR 6/6	Si	1.48	6.4	0.32	9.6	31.4	9	2.17 0.18	0.01 0.01	2.18 0.19
3Bf2	13.49-14.82	133	7.5YR 4/4	SL	0.17	6.6	0.27	61.2	29.2	9.5	1.15 0.13	0.08 0.02	1.23 0.15
3C	14.82+	-	10YR 7/2	S	0	3.8	0.1	92.5	3.8	3.7	0.06 0.01	0.04 0.02	0.10 0.03
						Paleosol 4							
Bm1	19.59-20.35	76	7.5YR 7/2	SL	0.88	6.2	0.22	66.2	19.9	13.8	0.74 0.02	0.09 0.02	0.83 0.04
Bf1	20.34-20.87	52	7.5YR 7/8	SL	1.02	6.3	0.62	67.6	20.3	12	2.81 0.62	0.04 0.01	2.85 0.63
Bf2	20.86-20.96	9	7.5YR 5/6	SL	0.75	6.4	1.18	64.3	19.6	16	4.40 1.46	0.05 0.01	4.45 1.47
Bf3	20.95-21.16	20	7.5YR 6/8	SL	0.67	6.4	0.31	78.5	10	11.4	1.07 0.36	0.11 0.06	1.18 0.42
R	21.26+												

[b] , calculated depths of horizons from the surface (vertical)

[c] , S, sandy; SL, sandy loam; Si, silty

sampling of the paleosols were carried out using methods outlined by the Soil Classification Working Group (1998). Chemical and mineralogical analyses were carried out in order to classify the paleosols with respect to modern soils. Analytical methods used are outlined in Sheldrick (1984). These include: pH in 0.01 M $CaCl_2$; C and N by a Leco-600 determinator; extractable Fe and Al by the ammonium oxalate and sodium pyrophosphate methods; particle size distribution by pipette analysis; and $CaCO_3$ equivalents (in %) by the gravimetric method. The results of these analyses are reported in Table III. Mineralogical analysis was carried out by x-ray diffraction using the <2 µm soil fraction (Table IV).

PALYNOLOGICAL ANALYSIS

Pollen samples were taken throughout the core. Six samples were found to contain pollen. These were analyzed for pollen content using standard palynological techniques involving treatment with hydrofluoric and hydrochloric acids,

TABLE IV

Mineralogical analysis of Bf horizons from the Pony Creek paleosols

Soil	Horizon	ISM	Mica	Kaolinite	Amphiboles	Quartz	Microcline	Plagioclase	X-ray amorphous
Paleosol 1	Bf1		*	*		***	**	*	**
Paleosol 2	2Bf1		**	**	*	***	**	**	**
Paleosol 3	3Bf1	*	**	**	*	***	*	**	**
Paleosol 4	Bf2		****	****		***	**		tr
	Bf3		***	***		***	**	**	tr

ISM, Interstratified minerals; tr trace, <1 %; * minor, 1-10 %; ** moderate, 11-25 %; *** major, 26-50 %; **** abundant, >50 %

potassium hydroxide, and acetolysis mixture (acetic anhydride and sulphuric acid) before mounting in silicon oil for counting. The six samples examined include samples 1-3 from Unit A and samples 4-6 from unit B (Figs. 2 and 3).

DESCRIPTION OF PONY CREEK CORE

The Pony Creek Core contains thick intervals of stony diamicton (Fig. 2, units A,C,D, and E) and thin laminated fine sand beds containing degraded plant remains (unit B). The upper three paleosols (1-3) developed under well-drained conditions in diamicton parent material (unit C). The lowest paleosol (4) developed in weathered bedrock (unit E). The diamictons are colluvial in origin and consist of angular pebble to cobble-size clasts of granodiorite in a coarse, sandy matrix. The granodiorite parent material is reflected in its quartzose-feldspathic mineralogy (Table IV). Kaolinite and mixed-layer clay minerals are products of pedogenesis.

SOIL CLASSIFICATION

An important measurement used in the classification of modern Canadian soils is the abundance of illuviated Fe and Al within B horizons. This is measured by the sodium-pyrophosphate extraction method (Soil Classification Working Group, 1998). However, illuviated Fe and Al in B horizons are tied up in short lived, chelated (organically bonded) compounds. Once a soil is removed from the surface environment through burial, the chelated Fe and Al oxidize to form inorganically bonded amorphous Fe and Al. Extraction and measurement of these forms of Fe and Al is accomplished through ammonium-oxalate extraction. Ammonium-oxalate-extracted Fe and Al values from paleosols are comparable to sodium-pyrophosphate-extraction values from modern soils (Wang and McKeague, 1982; McKeague *et al.*, 1983; Tarnocai, 1989; Tarnocai and Schweger, 1991). All of the paleosols are Podzols with well developed Bf horizons. Ammonium-oxalate-extractable Fe + Al concentrations all exceed 1 % (Table III). The Fe enrichment is indicated by the reddish colour of these horizons (*ca* 7.5Y 5/6).

Paleosol 1

This paleosol (unit C, Ah-Bf2) is noncalcareous and has a slightly acid reaction (pH 6.1-6.4). The Ah horizon has a sandy loam texture with relatively high organic carbon content (1.07 %). Despite this, it is light in colour (10YR 7/3). The underlying Bf1 and Bf2 horizons also have sandy loam textures and are slightly cemented, the Bf2 horizon more so than the Bf1. Of the four paleosols, paleosol 1 contains the smallest amount of kaolinite in its B horizon. As in all of the soils, the balance of the mineralogy reflects the granitic bedrock of the area.

Paleosol 2

This paleosol (unit C, 2Ah-2Bf2) is similar to paleosol 1, except it has a much deeper solum. It is noncalcareous to slightly calcareous with a slightly acid reaction (pH 6.1-6.4). The Ah horizon has a sandy loam texture and a moderately high organic carbon content (0.81 %). The calcium carbonate content (2.05 %) is probably due to carbonates leached out of paleosol 1. The two underlying Bf horizons also have sandy loam textures. The B horizons of this paleosol contain moderate amounts of kaolinite.

Paleosol 3

This paleosol (unit C, 3A-3C) is more developed than paleosols 1 and 2, and has the deepest solum (160 cm). It has moderate amounts of kaolinite and some minor amounts of interstratified minerals. It is noncalcareous to slightly calcareous with a slightly acid to neutral reaction (pH 6.3-6.8). The A horizon has a sandy loam texture and a low organic carbon content (0.56 %). The two underlying Bf horizons also have sandy loam to silty textures, and the thickest Bf horizons (136 cm in total), with the 3Bf2 horizon (133 cm) being the thickest of all.

Paleosol 4

This paleosol (unit E, Bm1-R) is similar to, but slightly more developed than, paleosol 3. It also has thick Bf horizons (81 cm in total), with the highest amounts of extractable Fe + Al. The ammonium-oxalate-extractable Fe + Al in these three Bf horizons ranges from 1.18 % to 4.45 %. This paleosol is noncalcareous with a slightly acid reaction (pH 6.2-6.4). The greatest amounts of kaolinite are found in this paleosol, suggesting an active and long period of weathering.

PALYNOLOGY

With the exception of unit A, colluvial diamicton is devoid of pollen or macro-organic detritus. Pollen data for units A (samples 1-3) and B (samples 4-6) are displayed in Figure 3. The pollen assemblages of unit B, principally unoxidized, laminated very fine sand with some degraded plant remains,

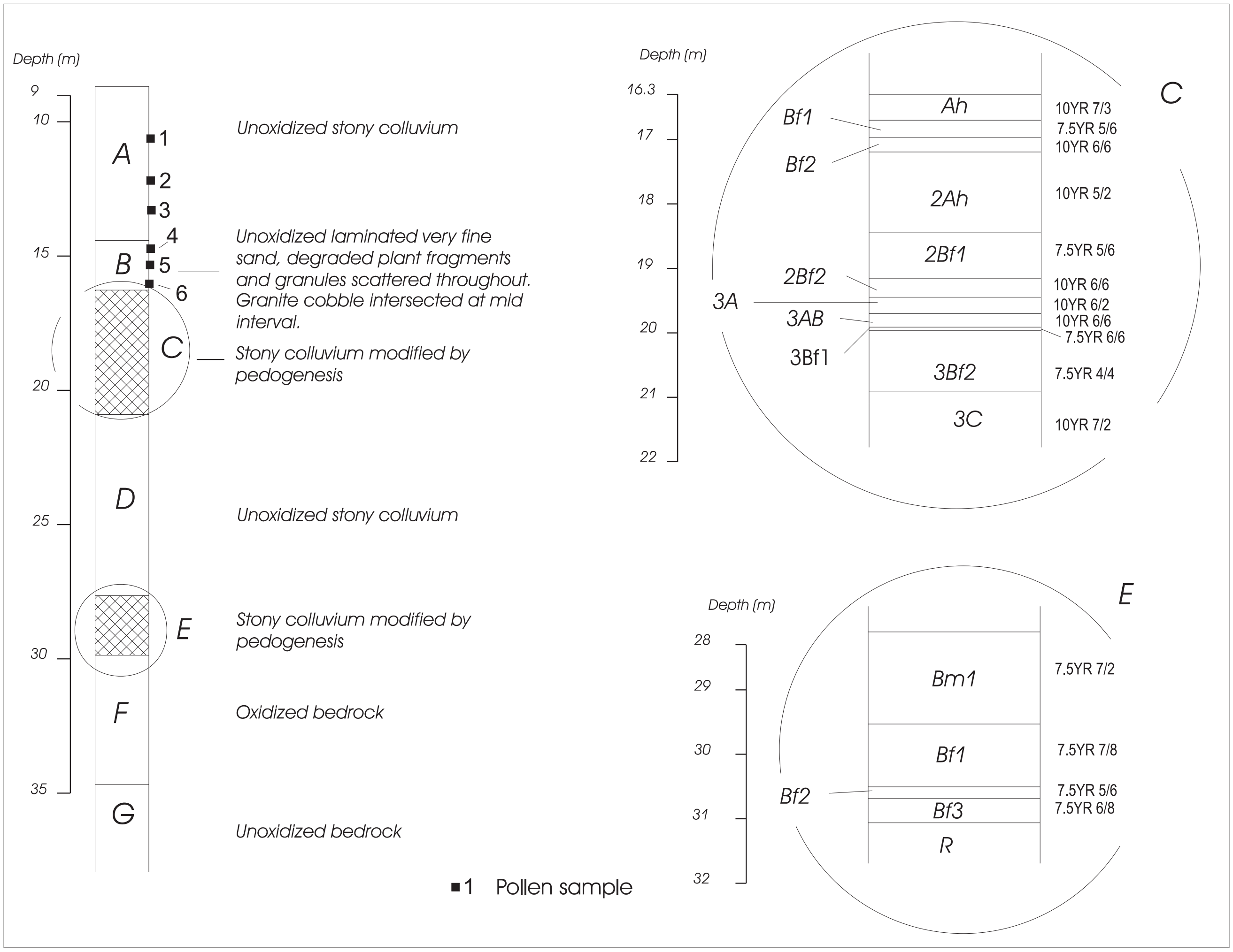

FIGURE 2. Schematic representation of the Pony Creek Core with details of paleosols and location of pollen samples.

Représentation schématique de la carotte de Pony Creek avec le détail des paléosols ainsi que la localisation des échantillons de paléosols.

contrast sharply with those of the overlying diamicton comprising unit A. *Picea* (spruce) pollen dominates samples 5 and 6, with values exceeding 60 %. Other arboreal taxa are minimal, with *Betula* (birch - probably a shrub birch taxon, based on size measurements) values of less than 10 %. *Pinus* (pine) pollen has values of 10 % or less and can probably be attributed to long-distance transport. Shrub and herb values are minimal. Cyperaceae (sedge family) values are 10 % or less. Pollen concentration values are 7,327 and 5,346 grains/cc in samples 5 and 6, respectively.

Sample 4 has an entirely different assemblage, which is dominated by more than 90 % *Shepherdia canadensis* (buffaloberry) pollen and only minor amounts of other taxa. The pollen concentration value for this sample is 75,922 grains/cc.

Samples 1 through 3 in unit A differ markedly from underlying samples. Cyperaceae, Gramineae (grass family) and herb pollen and fern (Pteridophyta) spores are prominent. *Artemisia* (sagebrush) reaches values of about 25 % in sample 2. *Picea* ranges from less than 10 % in sample 2 to 22 % in sample 3 and 36 % in sample 1. *Betula* (probably a shrub birch taxon) attains 30 % in sample 1 with lesser values below. *Pinus* is minimal along with low percentages for *Alnus* (alder) and *Salix* (willow). Pollen concentrations of 11,783, 4,631 and 1,103 grains/cc were determined for samples 1,2 and 3, respectively.

No modern surface pollen spectra studies are available from the area to relate the pollen spectra to the extant vegetation. Wang and Geurts (1991) have reviewed the late Quaternary pollen records from southwestern Yukon, and, although no profiles are available from the immediate area of the core site, some comparisons can be made with other pollen profiles of the region. *Pinus* pollen dominates the more southerly Yukon sites during the late Holocene reflecting the incursion of pine. Other profiles, particularly from sites at high elevations, have high values of *Betula* pollen indicating abundant shrub birch on the landscape. Some sites in areas supporting spruce forest closely resemble spectra of samples 5 and 6 with high *Picea* values and low values for other tree, shrubs and herbs.

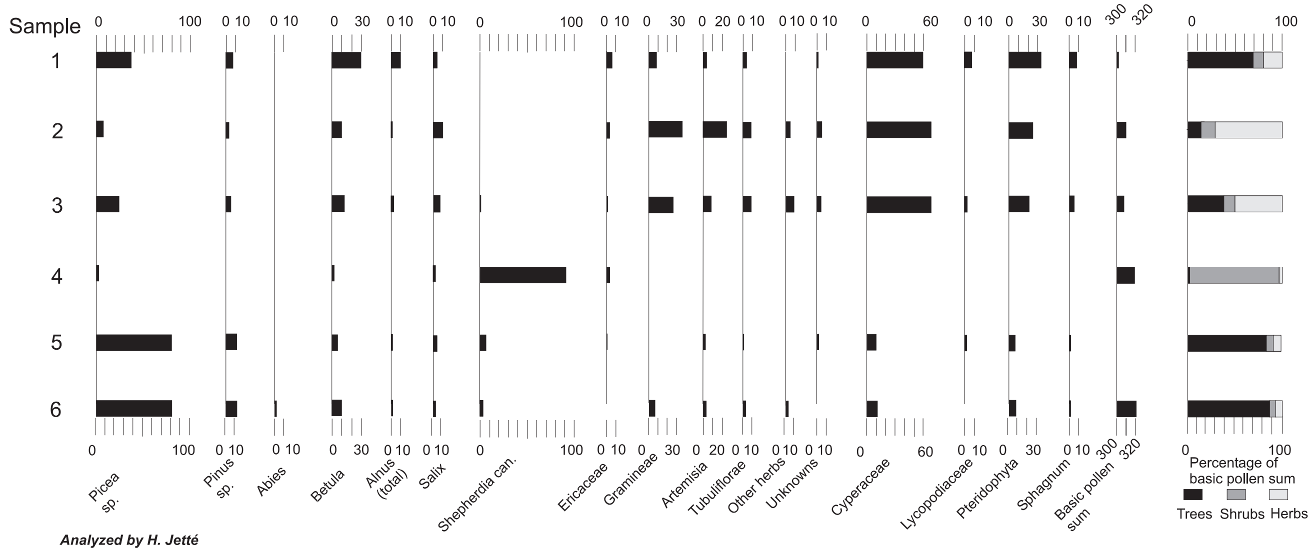

FIGURE 3. Pollen analysis of units A and B of the Pony Creek Core.

Diagramme pollinique des unités A e B de la carotte de Pony Creek.

Therefore, the pollen spectra of samples 5 and 6 with their abundant *Picea* indicate a spruce-dominated forest existed in the area. Few other tree taxa were present. The low values of *Pinus* can probably be attributed to long distance transport and the absence of pine species in the area. Birch may have been present but in low numbers and may have been a shrub birch judging by the small size of the grains. Whether or not the forest was closed or formed an open woodland similar to that present in the area today is difficult to determine although pollen concentration values suggest the latter. Modern forests include abundant aspen (*Populus tremuloides*) and balsam poplar (*P. balsamifera*) on lower slopes and in valleys along with minor paper birch (*Betula papyrifera)* (Rowe, 1959; Oswald and Senyk, 1977). Unfortunately, *Populus* pollen is usually not well represented in pollen spectra and there is no indication of it in these spectra. Spruce is the dominant taxon toward treeline along with shrub birch and willow at present.

The extremely large amount of *Shepherdia canadensis* (buffaloberry) pollen seen in sample 4 is somewhat anomalous as the pollen of this shrub is usually not abundant. It does form locally dense thickets in openings and dry forests and along rivers near the treeline (Viereck and Little, 1972). The high values indicate a very local abundance of the shrub, or maybe a time of transition from forest to tundra conditions.

The spectra of samples 1, 2 and 3, dominated by Cyperaceae and Gramineae, are representative of tundra environments found in high alpine tundra zones or in more northerly tundra environments (Birks, 1977, 1980; Wang and Geurts, 1991; Ritchie, 1984; Ritchie *et al.*, 1987) Spruce trees were less abundant than previously, especially in samples 2 and 3, and may not have been locally present or existed only in low numbers. Somewhat more spruce is suggested by the assemblage of sample 1, which indicates it may have been present as small stands or very open woodland areas. Birch, probably a shrub birch, was present along with minor amounts of alder and willow. The presence of sagebrush and other herbs indicate more open herbaceous tundra. The relatively high values of Pteridophyta spores suggest that ferns were present locally in some abundance. These results indicate that tundra conditions, similar to that near or beyond the contemporary treeline, prevailed at the time of deposition of the diamicton comprising unit A.

In summary, a spruce-dominated forest existed at the time of deposition of the fine laminated sand comprising unit B in contrast to the overlying diamicton (unit A) which was deposited when shrub or herb tundra conditions prevailed.

PALEOENVIRONMENTAL INTERPRETATION

The most important property of the Pony Creek paleosols for interpreting past climates is the presence of well-developed Bf (podzolic) horizons. Under the present climate, the nearest occurrence of such podzolic soil development is in the coastal forests of British Columbia, hundreds of kilometres to the south. Soil temperatures in these areas seldom drop below 0 °C. When frost occurs, it affects only the soil surface. The presence of such podzolic soil horizons in the alpine setting of the Dawson Range in central Yukon indicates dramatically warmer and wetter climates for thousands or tens of thousands of years.

The climates under which paleosols 1-4 formed contrast markedly with those of the Holocene and the last (Sangamonian) interglaciation in central Yukon. The climatic difference resembles that reported between the Diversion Creek paleosol or Stewart neosol and the Wounded Moose paleosols (Tarnocai *et al.*, 1985; Smith *et al.*, 1986; Tarnocai, 1987,1990; Tarnocai and Schweger, 1991). However, a correlation cannot be made with certainty between the Wounded Moose paleosols and those in the Pony Creek Core. This is because the Wounded Moose paleosols developed at elevations as much as 500 m lower than did the Pony Creek paleosols. Furthermore, the Pony Creek paleosols reflect individual periods of soil development, whereas the Wounded Moose soils likely reflect multiple periods of pedogenesis. Despite these uncertainties, the Pony Creek paleosol sequence provides an excellent opportunity for evaluating the soil development in upland settings during middle Pleistocene interglaciations.

PALEOENVIRONMENTAL RECORD OF THE PONY CREEK CORE AS A WHOLE

The sedimentary fill and the paleosols therein intersected by the Pony Creek Core are interpreted as having accumulated during alternating glacial and interglacial cycles. Diamicton units A and D are formed of physically weathered rocky detritus. They either lack pollen (unit D) or contain a tundra assemblage (unit A). They are interpreted as solifluction lobes or sediment gravity flows that entered the former meltwater channel during periods of full glacial climate, when the area was largely denuded of vegetation. The paleosols developed on the diamictons under forested conditions during interglaciation periods. The interval from paleosol 1 (top of unit C) up through the fine, stratified sediments of unit B into the colluvial diamicton of unit A best records one of these cycles. Paleosol 1 formed under a forest cover supported by a dramatically warmer and moister climate compared with contemporary conditions. The sediments in unit B indicate a subsequent marked cooling of the climate to one supporting a vegetation cover comparable with that existing today. Colluvial unit A was deposited after a periglacial climate largely denuded the area of vegetation.

Although four distinct paleosols are recognized, it is not clear whether paleosols 1-3 developed during a single interglacial period or during two or three interglacial periods. There is a lack of evidence for intervening periglacial climate between formation of these three paleosols. In the absence of evidence to the contrary, we have made the conservative assumption that they represent a single interglaciation during which nonperiglacial sedimentation resulted in soil burial.

AGE OF THE PONY CREEK PALEOSOLS

The paleosols can only be relatively dated as younger than the last pre-Reid glaciation. However, indirect evidence suggests that they predate the penultimate Reid glaciation. The Brunisolic Diversion Creek paleosol is widely developed on drift of Reid age and it is only slightly better developed than the Holocene Stewart neosol. Both developed under climates comparable to that of the present. All of the Pony Creek paleosols, however, developed under a markedly different climatic regime. Thus, they predate the Sangamonian Interglacial (oxygen isotope stage 5e) and, because no comparable soils have been observed on Reid drift, they likely predate the Reid Glaciation as well. The Reid Glaciation has not been directly dated, but Reid drift underlies the Old Crow and Sheep Creek tephras. These have been dated at *ca* 140 and 190 ka, respectively (Westgate, 1989; Berger *et al.*, 1996). On the basis of the present evidence, the soils developed during the middle Pleistocene (their age is bracketed between 0.99 Ma and *ca* 0.2 Ma).

DISCUSSION

The soil record in the Pony Creek Core implies that the mean annual temperature rose above 0 °C and precipitation was markedly enhanced for thousands of years at least twice during the middle Pleistocene. It is known that some past interglacials have been of longer duration and warmer that others in northwestern North America. Warming has been sufficient during some middle Pleistocene interglacials to eliminate permafrost and initiate deposition of speleothems in cave systems (Harmon *et al.* 1975; Lauriol *et al.,* 1997). Warm intervals also resulted in high sea level stands, such as the middle Pleistocene Wainwrightian transgression in western Alaska (Brigham-Grette and Carter, 1992; Brigham-Grette, 1996). Unfortunately, the Pony Creek paleosols have not been absolutely dated and therefore cannot be linked to any specific interglacial interval. Because of this, it is unclear as to what degree the mild and moist intervals, represented by the paleosols, are products of regional (on the scale of northwestern North America) to global scale climatic warming in excess of present (Holocene) interglaciation.

Other more local factors may have accentuated climatic moderation at the time of pedogenesis. Burn (1994) presented evidence for progressively increasing continentality in central and southern Yukon during the late Pliocene and Pleistocene. He concluded that widespread permafrost in southern and central Yukon is unique to the Holocene interglaciation. He linked the progressive continentality in central Yukon during the Pleistocene to progressive rising of the St. Elias Range during the same period. If this is the case, part of the climatic amelioration leading to the formation of Podzols in the Dawson Range was due to greater circulation of mild, moist air from the Pacific Ocean into central Yukon during winters at a time when the St. Elias Range was a less formidable climatic divide.

It might also be argued that the actual elevation at which these soils formed was lower than at present and uplift of the Yukon Plateaus following pedogensis was responsible for elevating them to their present montane setting. Thus, a component of the warmer climate indicated by the paleosols would be due to development at a lower elevation. The amount of uplift that has taken place in the Dawson Range since 0.99 Ma (the maximum age for the youngest pre-Reid glaciation and effective limiting age for the paleosols) is not known. However, there is evidence of a lack of river incision adjacent to the Dawson Range (and beyond the Reid glaciation ice limit). In the Fort Selkirk area, 80 km to the north, Yukon River flows about 10 m below the top of gravels deposited prior to *ca* 1.6 Ma (Jackson *et al.*, 1996; Jackson, in press). Although amount of regional uplift cannot be quantified on the basis of these relationships, it appears that the amount of uplift of the area during the Pleistocene has been insufficient to cause a major cycle of river incision. If this is the case, then the soils formed at an altitude close to their present altitude above contemporary sea level.

CONCLUSION

Drilling intersected four Podzolic paleosols within the fill of a buried meltwater channel last active during the youngest pre-Reid glaciation (0.99-0.78 Ma BP). The upper three paleosols may represent a single interglaciation. The lowest paleosol is separated from the upper three by a thick diamicton, apparently deposited under periglacial conditions. The uppermost paleosol is succeeded by stratified sediments yielding a boreal forest pollen assemblage. This is succeeded by a colluvial diamicton bearing a tundra pollen assemblage. The succession is interpreted as forming under alternating interglaciations and glaciations during the middle Pleistocene. The formation of Podzols at 1500 m a.s.l. in the Dawson Range indicates that the mean annual temperature rose above 0 °C in the alpine setting of the Dawson Range and, by inference, over large areas of central Yukon at of lower elevations for thousands of years between middle Pleistocene glaciations.

ACKNOWLEDGMENTS

The authors are grateful to Archer-Cathro and Associates (1981) Ltd. for drawing their attention to core DDH-115 and granting permission to sample and describe it. Help in the field by Steve Morison is also acknowledged. Thoughtful reviews by A.S. Dyke, C.R. Burn, and B. Lauriol added greatly to the clarity of this paper.

REFERENCES

Berger, G.W., Pewe, T.L., Westgate, J.A. and Preece, S.J., 1996. Age of the Sheep Creek Tephra (Pleistocene) in central Alaska from thermoluminescence dating of bracketing loess. Quaternary Research,45: 263-270.

Birks, H.J.B., 1977. Modern pollen rain and vegetation of the St. Elias Mountains, Yukon Territory, Canadian Journal of Botany, 55: 2367-2382.

——— 1980. Modern pollen assemblages and vegetational history of the moraines of the Klutlan Glacier and its surroundings, Yukon Territory, Canada. Quaternary Research, 14: 101-129.

Bostock, H.S., 1966. Notes on glaciation in central Yukon Territory. Geological Survey of Canada, Paper 65-56, 18 p.

Brigham-Grette, J., 1996. Paleoclimatic record from Pliocene-Pleistocene high-level deposits across central Beringia. AMQUA 1996 Program and Abstracts, p. 9-11.

Brigham-Grette, J. and Carter, L.D., 1992. Pliocene marine transgressions of northern Alaska: Circumarctic correlations and paleoclimatic interpretations. Arctic, 45: 74-89.

Burn, C.R., 1994. Permafrost, tectonics, and past and future regional climate change, Yukon and adjacent Northwest Territories. Canadian Journal of Earth Sciences, 31: 182- 191.

Foscolos, A.E., Rutter, N.W. and Hughes, O.L., 1977. The use of pedological studies in interpreting the Quaternary history of central Yukon. Geological Survey of Canada, Bulletin 271, 48 p.

Froese, D.G., Barendregt, R.W., Duk-Rodkin, A., Enkin, R.J., Baker, J. and Smith, D.G., 1997. Sedimentology and paleomagnetism of Pliocene-Pleistocene lower Klondike valley terrace sediments, west-central Yukon. 1997 Abstracts, Canadian Quaternary Association, p. 24.

Harmon, R.S., Ford, D.C. and Schwarcz, H.P., 1975. Interglacial chronology of the Rocky and Mackenzie Mountains based upon ^{230}Th-^{234}U dating of calcite speleothems. Canadian Journal of Earth Sciences, 14: 2543-2552.

Heginbottom, J.A., Dubreuil, M.A. and Harker, P.T., 1995. Canada Permafrost. Map 2.1, National Atlas of Canada, 5th edition, Government of Canada, Ottawa, scale 1:5 000 000.

Hughes, O.L., 1990. Surficial geology and geomorphology, Aishihik Lake, Yukon Territory. Geological Survey of Canada Paper 87- 29, 23 p.

Hughes, O.L., Campbell, R.B., Muller, J.E. and Wheeler, J.O., 1969. Glacial limits and flow patterns, Yukon Territory, south of 65 degrees north latitude. Geological Survey of Canada Paper 68-34, 9 p.

Hughes, O.L., Rutter, N.W. and Clague, J.J., 1989. Yukon Territory (Quaternary stratigraphy and history, Cordilleran Ice Sheet), p. 58-62. *In* R.J. Fulton, ed., Quaternary Geology of Canada and Greenland. Geological Survey of Canada, Geology of Canada, 1 (*also* Geological Society of America, The Geology of North America, K-1).

Jackson, L.E., Jr., in press. Terrain inventory and Quaternary history of Carmacks map area, 115I, Yukon. Geological Survey of Canada Bulletin.

——— 1997a. Surficial geology, Victoria Creek, Yukon Territory. Geological Survey of Canada map 1876A, scale 1:100,000.

——— 1997b. Surficial geology, Tantalus Butte, Yukon Territory. Geological Survey of Canada map 1879A, scale 1:100,000.

Jackson, L.E., Jr., Barendregt, R., Baker, J. and Irving, E., 1996. Early Pleistocene volcanism and glaciation in central Yukon: New chronology from field studies and paleomagnetism. Canadian Journal of Earth Sciences, 33: 904-916.

Jackson, L.E. Jr., Ward, B.C., Duk-Rodkin, A. and Hughes, O.L., 1991. The last Cordilleran ice sheet in Yukon Territory. Géographie physique et Quaternaire, 45: 341-354

Lauriol, B., Ford, D.C., Cinq-Mars, J. and Morris, W.A. 1997. The chronology of speleothem deposition in northern Yukon and its relationships to permafrost. Canadian Journal of Earth Sciences, 34: 902-911.

Mathews, W.H., 1986. Physiographic map of the Canadian Cordillera. Geological Survey of Canada, Map 1701, scale 1:5 000 000.

McKeague, J.A., Wang, C., Coen, J.M., DeKimpe, C.R., Lavadiere, M.R., Evans, L.J., Kloosterman, B. and Green, A.J., 1983. Testing chemical criteria for spodic horizons on podzolic soils in Canada. Soil Science Society of America Journal, 47: 1052-1053.

Oswald, E.T. and Senyk, J.P., 1977. Ecoregions of Yukon Territory, Canadian Forestry Service, 115 p.

Ritchie, J.C., 1984. Past and Present Vegetation of the Far Northwest of Canada. University of Toronto Press, 251 p.

Ritchie, J.C., Hadden, K.A. and Gajewski, K., 1987. Modern pollen spectra from lakes in arctic western Canada, Canadian Journal of Botany, 65: 1605-1613.

Rowe, J.S., 1959. Forest Regions of Canada. Department of Northern Affairs and Natural Resources, Forestry Branch Bulletin 123, 71 p.

Sheldrick, B.H., 1984. Analytical methods manual. Land Resource Research Institute, Agriculture Canada, Ottawa, L.R.R.I. Contribution 84-30.

Smith, C.A.S., Tarnocai, C. and Hughes, O.L., 1986. Pedological investigations of Pleistocene glacial drift surfaces in the central Yukon. Géographie physique et Quaternaire, 15: 29- 37.

Soil Classification Working Group, 1998. The Canadian System of Soil Classification (3rd ed.). Agriculture and Agri-Food Canada, Ottawa, Publication 1646, 187 p.

Tarnocai, C. 1987. Quaternary soils, p.16-23. *In* S.R. Morison and C.A.S. Smith, eds., Guidebook to Quaternary Research in Yukon. XII INQUA Congress, Ottawa, Canada, National Research Council of Canada, Ottawa, p. 16-23.

——— 1989. Paleosols of northwestern Canada, p. 39-44. *In* L.D. Carter, T.D. Hamilton and J.P. Galloway. eds., Late Cenozoic history of the interior basins of Alaska and Yukon. United States Geological Survey Circular 1026.

——— 1990. Paleosols of the interglacial climates in Canada. Géographie physique et Quaternaire, 44: 363-374.

Tarnocai, C. and Schweger, C.E., 1991. Late Tertiary and early Pleistocene paleosols in northwestern Canada. Arctic, 44: 1-11.

Tarnocai, C. and Smith, C.A.S., 1989. Micromorphology and development of some central Yukon paleosols, Canada. Geoderma, 45: 145-162.

Tarnocai, C., Smith, C.A.S. and Hughes, O.L., 1985. Soil development on Quaternary deposits of various ages in the central Yukon Territory. *In* Current Research, Part A, Geological Survey of Canada Paper 85-1A: 229-238.

Viereck, L.A. and Little, E.L., Jr., 1972. Alaska Shrubs and Trees. U.S. Department of Agriculture, Forest Service, Agriculture Handbook 410, 265 p.

Wahl, H.E., Fraser, D.B., Harvey, R.C. and Maxwell, J.B., 1987. Climate of Yukon. Environment Canada, Atmospheric Environment Service, Climatological Studies 40, 319 p.

Wahl, H.E. and Goos, T.O., 1987. Climate. *In* S.R. Morison, and C.A.S. Smith, XIIth INQUA congress field excursions A20a and A20b: 7-12.

Wang, C. and McKeague, J.A., 1982. Illuviated clay in sandy Podzolic soils of New Brunswick. Canadian Journal of Soil Science, 62: 78-89.

Wang, X-C and Geurts, M-A., 1991. Late Quaternary pollen records and vegetation history of the southwest Yukon Territory: A review. Géographie physique et Quaternaire, 45: 175-193.

Westgate, J.A., 1989. Isothermal plateau fission-track ages of hydrated glass shards from silicic tephra beds. Earth and Planetary Science Letters, 95: 226-234.