Available online at www.sciencedirect.com
SCIENCE DIRECT®
ACADEMIC PRESS
QUATERNARY RESEARCH
Quaternary Research 60 (2003) 9–18
www.elsevier.com/locate/yqres

Stratigraphy, fossils, and age of sediments at the upper pit of the Lost Chicken gold mine: new information on the late Pliocene environment of east central Alaska

John V. Matthews Jr.,[a,*] J.A. Westgate,[b] Lynn Ovenden,[c] L. David Carter,[d] and Thomas Fouch[e]

[a] *Ohana Productions, 1 Red Maple Ln, Hubley, Nova Scotia B3Z 1A5, Canada*
[b] *Dept. of Geology, University of Toronto, Toronto, Ontario M5S 3B1, Canada*
[c] *RR 3, Casselman, Ontario K0A 1M0, Canada*
[d] *201 Libby St., Sequim, WA 98382, USA*
[e] *The Geological Society of America, P.O. Box 9140, Boulder, CO 80301-9140, USA*

Received 14 November 2002

Abstract

The "upper pit" at the Lost Chicken placer gold mine in east central Alaska contains fossils that provide information on the flora and insect fauna of interior Alaska just before the onset of global cooling at 2.5 myr. Fossils come from sediments interbedded with the Lost Chicken tephra (dated at 2.9 ± 0.4 myr—early Late Pliocene) and portray the floodplain and valley of a small creek within a region dominated by a coniferous forest richer in genera and species than the present one. Climate was wetter and less continental, and there was probably little or no permafrost. At least one other Pliocene tephra (the Fortymile tephra) occurs at the site and is also associated with plant and insect fossils. Among these fossils are extinct plants and insects like those found at other Tertiary sites in northern Canada and Alaska. The Lost Chicken sequence is the same age as the Beaufort Formation on Meighen Island, more than 1000 km to the north. Like Lost Chicken, Meighen Island sediments contain fossils representing a diverse boreal environment. This shows that the latitudinal climate gradient during early Late Pliocene time was shallower than at present and the boreal forest had a far greater latitudinal span than now.

Introduction

In 1966, at the suggestion of Troy Péwé, one of the authors (JVM) and R. D. Guthrie visited the Lost Chicken placer mine in the Fortymile District of eastern Alaska (Fig. 1). We examined two placer operations at Lost Chicken Creek: one above the highway (upper pit, hereafter LC-II) and another below the road near the present river floodplain. Even though the lower workings had yielded many Pleistocene bones (Porter, 1988), we were drawn to LC-II because it contained two prominent autochthonous peat horizons. They contained poorly preserved, partly silicified insect fossils representing taxa other than those JVM had seen at late Quaternary sites, and a pollen sample from one yielded significant amounts of pine pollen (Matthews, 1970a), which was also at variance with what was typical of late Quaternary pollen samples. JVM revisited LC-II in 1974 and discovered a tephra (Lost Chicken tephra or LCT) interbedded with one of the peats. This was an exciting find because it offered the possibility of dating the peats and their fossils. By late 1974, we suspected that the peats were older than the late Quaternary, hence beyond ^{14}C range. Further studies at LC-II in 1991 by an interdisciplinary research group from the Geological Survey of Canada, the U.S. Geological Survey, and other institutions further expanded the fossil collections and refined the stratigraphy and paleomagnetism of the sediments (White et al., 1997).

The first dates on LCT confirmed its pre-Quaternary age and subsequent analyses (see below) showed conclusively

* Corresponding author.
E-mail address: ohana@hfx.eastlink.cd (J.V. Matthews).

0033-5894/03/$ – see front matter © 2003 University of Washington. Published by Elsevier Inc. All rights reserved.
doi:10.1016/S0033-5894(03)00087-5

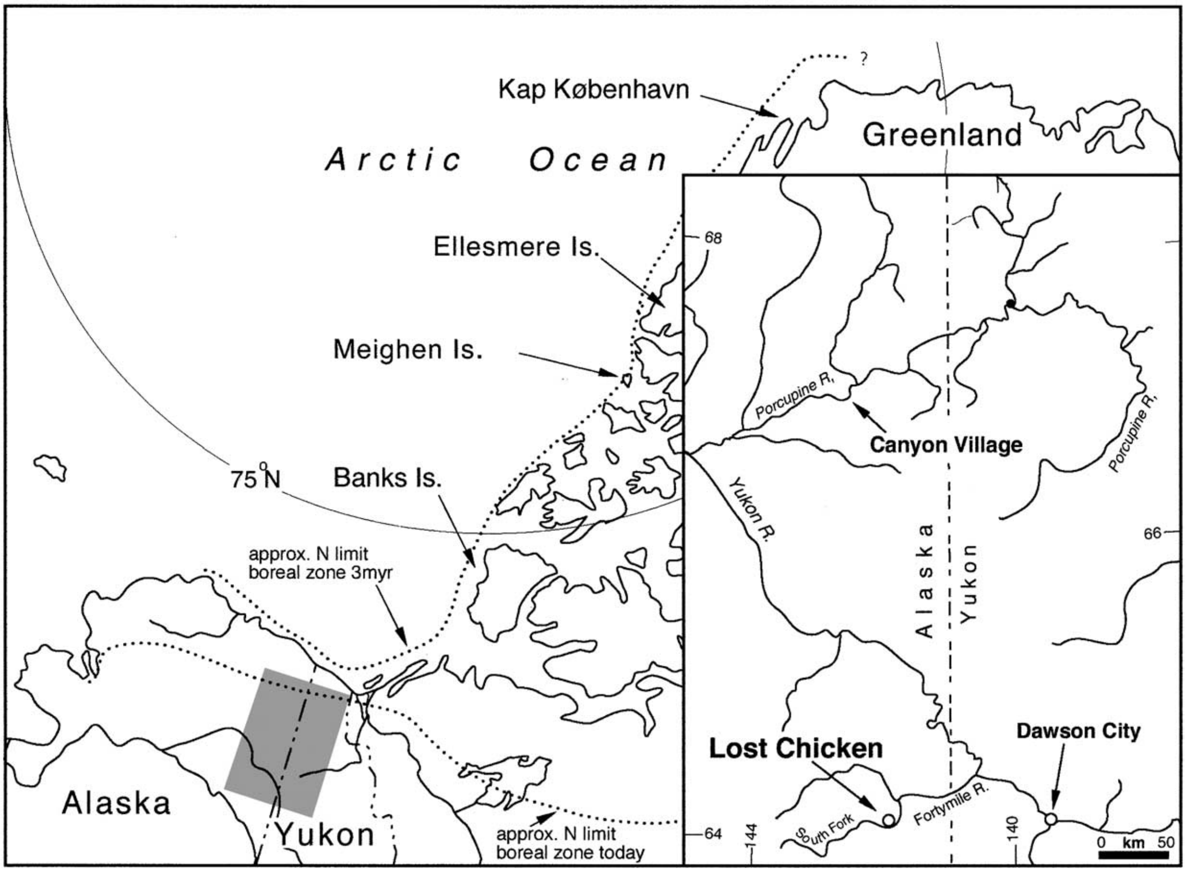

Fig. 1. Maps showing location of Lost Chicken locality in eastern Alaska and other sites mentioned in the text. Note the extent of the boreal zone 3 myr ago (early Late Pliocene). Chicken and Lost Chicken creeks both occupy the area covered by the dot for Lost Chicken.

that LCT is nearly 3 myr in age (early Late Pliocene). In this paper we describe the stratigraphy of LC-II, discuss the dating of LCT, and present a brief review of the fossil evidence and its regional implications.

Geologic setting

Lost Chicken Creek is a small tributary of the South Fork of the Fortymile River in east central Alaska (Fig. 1). The valley of Lost Chicken Creek extends southeast from a wind gap that separates the Lost Chicken Creek watershed from the much larger Chicken Creek drainage basin. About 1 km from the wind gap, the valley of Lost Chicken Creek opens onto a fluvial terrace remnant of the South Fork. Here we are concerned only with the placer sediments that are graded to this terrace remnant that contains LC-II.

In the summer of 1991, the active cut of LC-II (Fig. 2) was about 120 m long and faced northeast. Strata exposed in this cut include fluvial and associated organic sedimentary and forest floor deposits. The exposure records several episodes of stream deposition that interrupted periods of accumulation of organic matter on forest floors and of peat in small wetlands. Some episodes of deposition are separated only by erosional boundaries but most of the time accounted for in LC-II exposure is probably represented by periods of peat accumulation. There are no evident paleosols or other evidence of protracted weathering (C.A. Scott Smith, personal communication, 2000).

The LC-II section is divided into seven units (A–G) (Fig. 3). Unit A is poorly exposed and consists of trough cross-bedded sand and structureless mud (mixtures of sand, silt, and clay), capped by a thin peat. Composed primarily of gravel and gravelly coarse sand with rare organic-rich mud lenses, Unit B was probably deposited in the central portion of a low sinuosity channel. Both Units C and D are composed of very coarse to fine-grained sediments. Local scour–fill structures are common, as are local upward-fining cycles. The upper few centimeters to millimeters of each cycle are composed mostly of mud and silt. Unit E is compositionally similar to Units C and D except for numerous organic mud beds ranging from 1 to 10 cm thick. Unit F is composed of coarse to very fine-grained sand, silt, and mud occurring in scour–fill and trough-form beds. Unit G consists of colluvial and alluvial sand and mud that is chaotic to locally well bedded and contains abundant detrital organic debris. Ice wedges occur throughout this deposit and their tops are at several levels.

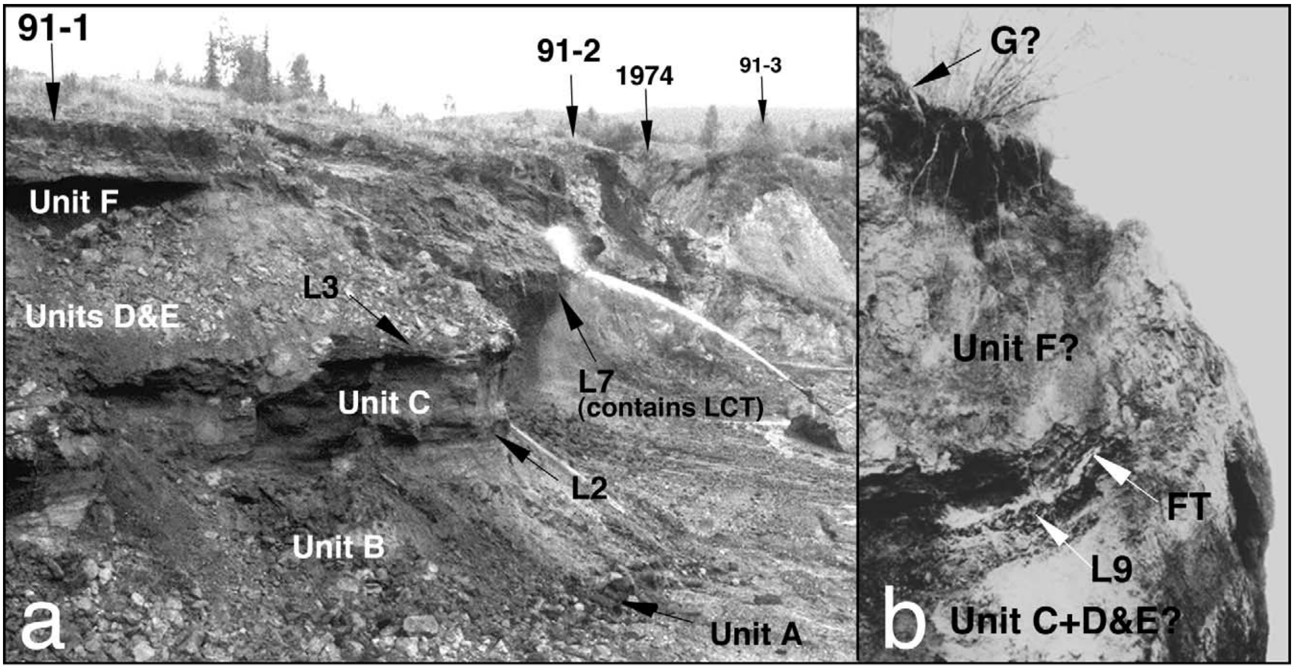

Fig. 2. (a) View of LC-II looking west along the section from the top of the exposure near station 91-1 to 91-3 in a gulley at the far end of the section. At the time of the photo, the section was being "monitored" by a jet of high velocity water (striking the section just below 91-2) in order to remove overlying frozen gravels and silt. LCT = Lost Chicken tephra. (b) Station 91-3, showing upper part of the slumped and thawed exposure. FT = Fortymile tephra (maximum thickness approximately 10 cm).

The prominent organic beds at LC-II (Figs. 2 and 3) are the source of most fossils discussed here. L2 and L3 are developed on scour surfaces, whereas L1, L4, L6, and L7 are apparently the uppermost and finest-grained portions of scour–fill cycles. L1 probably represents a short-lived forest that was subsequently buried by the deposits of a stream. L2 also represents a brief forest interval. It marks the boundary between braided, bedload stream deposits and those of mixed bedload and suspended load streams. Organic beds L4, L6, and L7 probably mark slow deposition of organic matter in wetlands marginal to streams or in abandoned channels.

Correlation of Section 91-3 with the main part of the exposure is tentative partly because the tephra exposed there is not LCT and also because the section is thawed, slumped, and more than 100 m from the main section. L9 (Fig. 2b) is more silty than other organic units in the section.

Lost Chicken tephra (LCT), up to 10 cm in thickness, occurs at several places in the exposure: at one locality within peat unit L7; at another, just above a peat thought to be correlated with L7. At 91-1 (Fig. 2) there is a disseminated partially cemented tephra associated with the L2 forest bed. We do not at this juncture know if this tephra is LCT. As indicated above, insect fossils from sample 66-1 in L6 were slightly silicified, possibly due to weathering of a now obscured tephra in the peat. A tephra interbedded with peaty organics at the top of sequence 91-3 was at one time assumed to be LCT. Since then it has been shown to be distinct from LCT and is here named the Fortymile tephra (FT in Fig. 3).

Age and correlation

The LC-II site owes its significance in part to the fact that organic deposits bearing unusual and environmentally significant fossils are associated with two distinct tephra beds, Lost Chicken tephra (LCT) and Fortymile tephra (FT).

LCT has been dated. One sample from the 1974 section (LCT!: UA771) is composed mostly of pumiceous glass, although some poorly vesicular glass is present. Plagioclase feldspar and biotite predominate in the crystal fraction, which also contains some basaltic hornblende, hornblende, and FeTi oxides. The glass shards have a rhyolitic composition and show small shard-to-shard variation, as is seen by the low standard deviation in Table 1. These characteristics, together with a low abundance of rare-earth elements in the glass (Westgate et al., 1985), indicate a Type-II tephra derived from a vent in the Wrangell volcanic field (Preece et al., 1999). The composition of glass shards in another sample from section 91-2 (tephra bed K-91-6-26A) is clearly the same as in sample UA771, justifying the correlation shown in Fig. 3.

Unfortunately, no petrographic details are available on FT. The only available compositional information (Table 1) is from a small sample of glass shards (K-91-6-27A) that was sent to the USGS laboratory at Menlo Park for major-

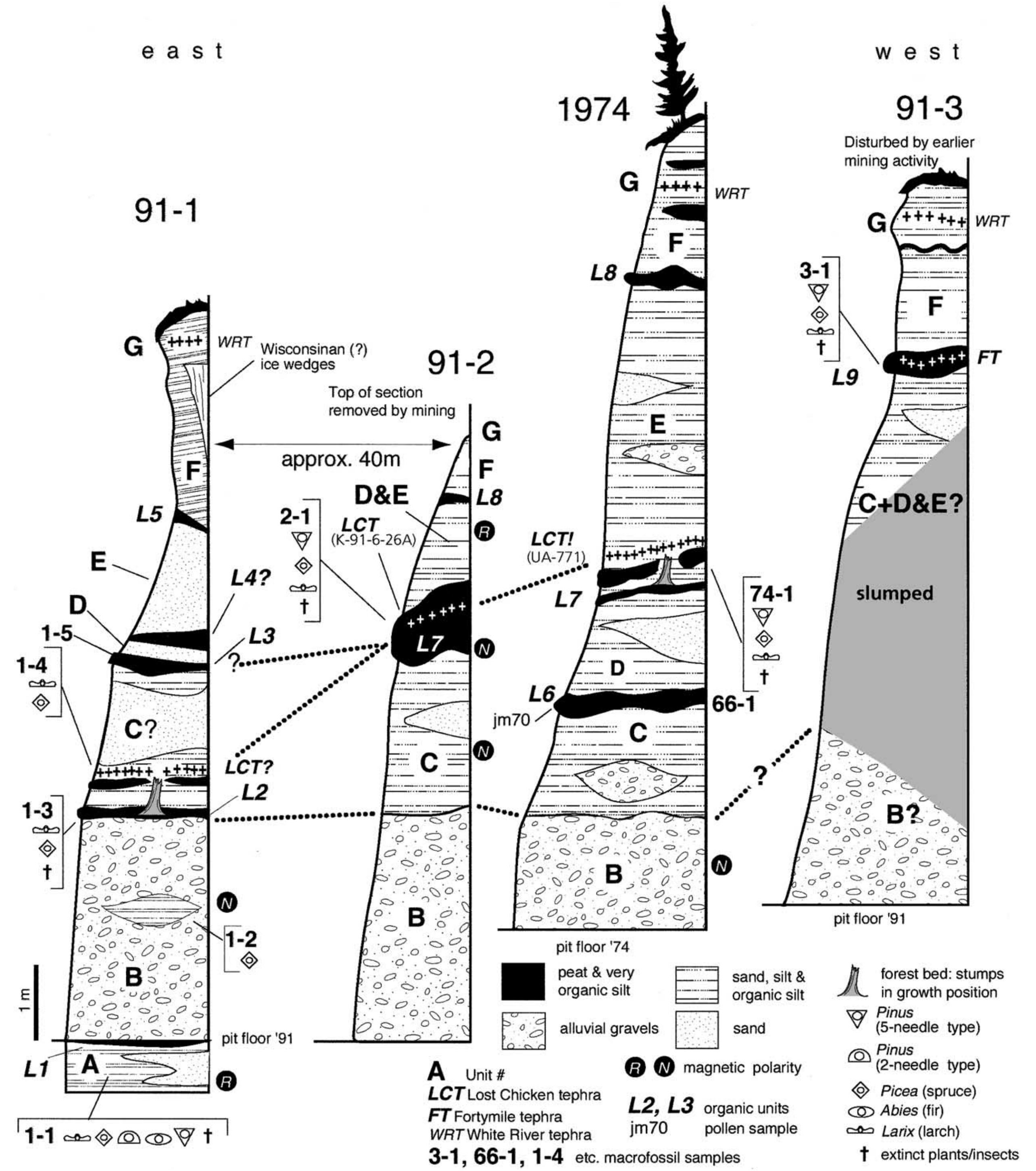

Fig. 3. Stratigraphy of the LC-II exposure based on studies in 1966, 1974, and 1991. The 91-3 section is located approximately 150m from 91-2 and 1974 (see Fig. 2). "jm70" indicates the level of a pollen sample studied by Matthews (1970a).

element characterization (Andrei Sarna-Wojcicki, personal communication, 2000). The glass has a homogeneous, rhyolitic composition, but is more basic than that of LCT; Ti, Al, Fe, Mg, and Ca contents are all distinctly higher in FT.

An earlier study placed the age of LCT in the range of 1.72–2.60 myr (Naeser et al., 1982). The younger estimate is a glass-fission-track age but is a minimum value because no correction was applied for partial track fading. The older fission-track age is based on zircons, but the presence of abundant defects in the crystals led to some uncertainty as to its accuracy (Table 2). Accurate age estimates can be obtained on hydrated glass shards by use of the isothermal

Table 1
Major-element composition of glass shards from tephra beds at Lost Chicken, Alaska

	Lost Chicken tephra UA771	Lost Chicken tephra K-91-6-26A	Fortymile tephra K-91-6-27A
SiO_2	77.09 ± 0.23	77.05 ± 0.29	70.01 ± 0.21
TiO_2	0.07 ± 0.03	0.07 ± 0.02	0.60 ± 0.04
Al_2O_3	13.57 ± 0.12	13.46 ± 0.20	15.16 ± 0.16
FeO_t	0.80 ± 0.08	0.74 ± 0.08	2.83 ± 0.08
MgO	0.13 ± 0.02	0.13 ± 0.02	0.74 ± 0.04
CaO	0.75 ± 0.07	0.69 ± 0.05	2.18 ± 0.04
MnO	0.06 ± 0.03	0.07 ± 0.04	0.07 ± 0.04
Na_2O	4.43 ± 0.11	4.70 ± 0.13	5.37 ± 0.10
K_2O	3.10 ± 0.15	3.09 ± 0.05	3.03 ± 0.06
H_2O_d	7.31 ± 0.78	8.10 ± 0.56	5.23 ± 1.41
n	20	11	7

Notes. Analyses (wt. %) by C. Meyer using JEOL electron microprobe at United States Geological Survey, Menlo Park, CA (courtesy of Andrei Sarna-Wojcicki). Analyses recast to 100% on a water-free basis; mean and one standard deviation given. FeO_t = total iron oxide as FeO; H_2O_d = water, by difference; *n* = number of analyses. See Fig. 3 for details on stratigraphic setting of these samples. Analyses of individual samples are available from JAW.

plateau fission-track (ITPFT) method (Westgate, 1989). A single heat treatment of 150°C for 30 days is sufficient to correct fully for partial track fading. The glass-ITPFT age estimate for LCT is 2.91 ± 0.44 myr (Table 2). Although the error is large, this age estimate overlaps with the zircon-fission- track age of 2.60 ± 0.45 myr at the 1σ level.

The paleomagnetic properties of the host sediments (H. Rieck, unpublished data shown in Fig. 3) provide a further constraint on the age of LCT. Unit C sediments just below LCT at Section 91-2 have a normal remanent magnetic polarity (Fig. 3), which suggests that LCT was deposited during the youngest normal subchron of the Gauss chron, that is, between 2.581 and 3.040 myr (Cande and Kent, 1995). The reversed magnetic polarity of Unit A likely means that it was deposited during the Kaena subchron (3.040–3.110 myr; Cande and Kent, 1995), whereas the reversed magnetic polarity of Units D and E, which occur above LCT, suggests that these silty sediments accumulated during the early part of the Matuyama chron.

The age of sediments at Section 91-3 must await further study of FT; however, fossils from the same level dictate an age no younger than Late Pliocene (see below).

Plant and arthropod macrofossils

See Fig. 3 for location and position of macrofossil samples. Units E and F were not sampled for fossils. Plant macrofossils previously mentioned in Matthews and Ovenden (1990) came from the lower peat (66-1) and the set of peats (L7) immediately below LCT (74-1) (Fig. 3). Insect fossils listed in Elias and Matthews (2002) come from

Table 2
Glass-fission-track age of Lost Chicken tephra, Alaska

Sample number (analyst)	Date irradiated	Spontaneous track density 10^2 t/cm^2	Induced track density 10^5 t/cm^2	Track density on muscovite detector over dosimeter glass 10^5 t/cm^2	Etching conditions HF:temp:time %: °C: s	D_s μm	D_i μm	D_s/D_i	Age myr
UA771* (NN)	7-12-77	16.70 ± 1.46 (130)	1.28 ± 0.02 (4167)	4.13 ± 0.05 (8233)	24: 23: 45	nd	nd	nd	1.72 ± 0.16
UA771** (JW)	17-12-90	19.09 ± 1.32 (209)	1.56 ± 0.02 (6269)	7.49 ± 0.04 (39148)	26: 25: 100	5.57 ± 0.15	5.62 ± 0.08	0.99 ± 0.03	2.91 ± 0.44

Notes. The population-subtraction method was used; details are given in Westgate et al. (1997). UA771* is uncorrected for partial track fading and is a minimum age estimate (Naeser et al., 1982). UA771** is an isothermal plateau age; correction for partial track fading is done by heating the induced and spontaneous aliquots at 150°C for 30 days (Westgate, 1989). Ages calculated using the ζ approach and $\lambda_D = 1.551 \times 10^{-10}$yr^{-1}. ζ value is 318 ± 3 based on six irradiations at the McMaster Nuclear Reactor, Hamilton, Ontario, using the NIST SRM 612 glass dosimeter and the Moldavite tektite glass (Lhenice locality) with an $^{40}Ar/^{39}Ar$ plateau age of 15.21 ± 0.15 myr (Staudacher et al., 1982). Standard error ($\pm 1\sigma$) on age estimate is calculated according to Bigazzi and Galbraith (1999). Area estimated using the point-counting method (Sandhu et al., 1993). D_s = mean spontaneous track diameter, D_i = mean induced track diameter, nd = not determined, NN = Nancy Naeser, and JW = John Westgate. Number of tracks counted is given in brackets. Lost Chicken tephra has a zircon-fission-track age of 2.60 ± 0.45 myr (Naeser et al., 1982).

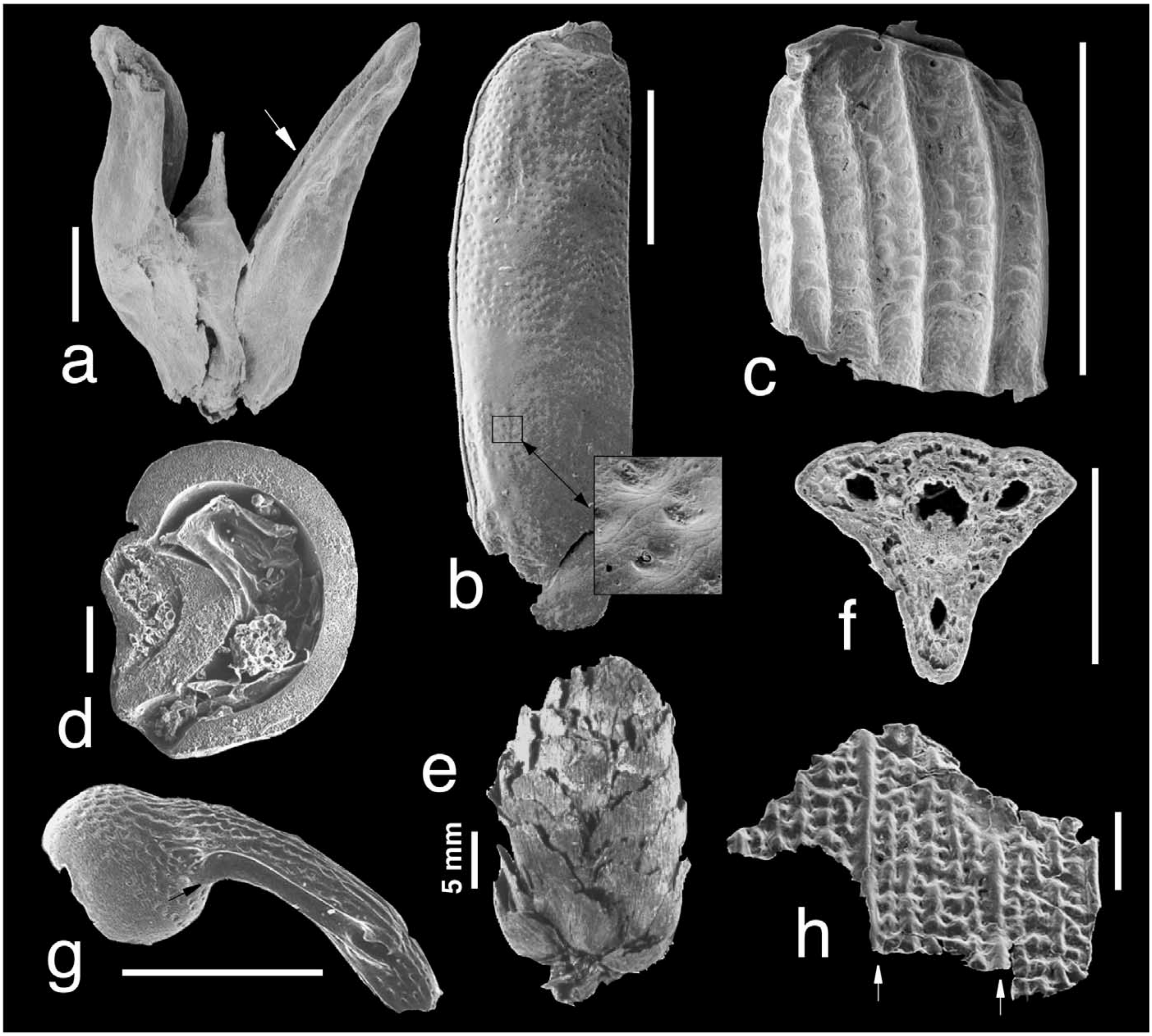

Fig. 4. SEM micrographs of plant (a,d,e,f) and Coleoptera (beetle) macrofossils (b,c,g,h) from the Lost Chicken site. Scale bar = 500 μm unless otherwise indicated. See Fig. 3 for sample position (a) *Myrica arctogale* Benn (Myricaceae); endocarp with attached lateral lobes; GSC- 108045; sample 1-1(MRA-6-26-91-7). Arrow indicates right lobe. Arrow head indicates approximate length of lobes in the modern *Myrica gale*. (b) *Asaphidion* sp. cf. *A. yukonense* Wick. fossil (GSC-108055), Sample 1-1(MRA-6-25- 91-5)(Carabidae). Inset shows elytral microsculpture. (c) *Micropeplus hopkinsi* Matthews (Micropeplinae) left elytron; GSC-108053; Sample 1- 1(MRA-6-26-91-1). (d) *Epipremnum crassum* C. & E. Reid (Araceae) seed; GSC-108050; Sample 3-1 (MRA 6-27-91-2). View shows a cross section of the seed. (e) *Larix* sp. (Pinaceae), female cone; GSC-108049; Sample 1-3 (MRA-6-24-91-3). Some of the bracts subtending the cone scales protrude beyond the margin of the cone scale, a characteristic which distinguishes this and other LC-II *Larix* cones from cones of the modern tamarack (*Larix laricina*). (f) *Pinus* (*Strobus*) sub-sect. *Cembrae* (Pinaceae), leaf cross-section; GSC-108048; Sample 3-1(MRA-6-27-91-2). The upper two resin canals are positioned well away from the adaxial leaf surface, unlike any present North American five-needle pine. (g) *Otibazo* sp. (Coleoptera: Curculionidae), head; GSC-108058, sample 74-1. Arrow indicates the eye, consisting of a single facet. (h) *Carabus* cf. *nemoralis* (Coleoptera: Carabidae); elytral fragment; GSC-108056; Sample 3-1(MRA6-27-91-2). The elytral sculpture consists of major ridges (arrows) with foveate interruptions separated by five somewhat interrupted nonfoveate ridges. The current N. Am. species in this group was introduced from the Old World.

several of the localities, but primarily sample 1-1 and 2-1. A complete list of all macrofossils is available from the senior author.

Among the plant fossils from sample 1-1 in Unit A are cones and/or needles of two-needle and five-needle pine (*Pinus*), spruce (*Picea*), larch (*Larix*), and fir (*Abies*), as well as many seeds and fruits. The larch (*Larix*) cones (Fig. 4e) resemble cones described as *Larix groenlandii* from the Late Pliocene Kap Kobenhavn site in northern Greenland (Fig. 1) (Bennike, 1990). Similar larch cones occur at a number of other late Tertiary arctic/subarctic sites (Matthews, unpublished report, available from the senior author). Another distinctive plant fossil, one that also occurs commonly at other late Tertiary sites, is an extinct form of sweet gale—*Myrica arctogale* (Fig. 4a) (Bennike, 1990; Matthews and Ovenden, 1990; Matthews et al., 1990).

Insect fossils are relatively abundant in sample 1-1 from Unit A. Many represent taxa that live on silty flood plains within present day forested regions. Some of the fossils, e.g., elytra of the ground-beetle *Asaphidion* (Fig. 4b), differ enough from modern counterparts to be considered an undescribed or possibly extinct species. The ground-beetle *Diacheila matthewsi* Böcher is also extinct and a good indicator of Pliocene age (Matthews and Telka, 1997; Matthews, unpublished report, available from the senior author). The tiny beetle *Micropeplus hopkinsi* (Fig. 4c) is also extinct (Matthews, 1970b) and, to date, restricted to Pliocene and older deposits.

The only plant and insect fossils from Unit B come from a small lens (1–2 in Fig. 3) within the gravels. None of the fossils has definite age implications and all that can be concluded is that the sediments were deposited when LC-II was below treeline.

The peat unit labeled 66-1 (=L6) on the 1974 section (Fig. 3) was the first from LC-II to yield insect fossils. However, unlike fossils from other levels, the fossils from the peat were slightly silicified, almost as if they were associated with a tephra in which the silica has been mobilized. Tephra was not seen at the time of sampling.

A pollen sample from peat 66-1 contained slightly more than 15% pine pollen and 35% spruce pollen (Matthews, 1970a), similar to unpublished pollen results from other LC-II sites (White et al., 1999). Compared to Quaternary pollen samples from sites where pine was known to have been growing, percentage of pine pollen at LC-II seems abnormally low. However, other Arctic sites of late Tertiary age that contain pine macrofossils also show relatively low pine percentages (Matthews, unpublished report, available from the senior author).

All of the LC-II byrophyte and vascular plant fossils listed in Matthews and Ovenden (1990) come from the two peats (L7) associated with the dated LCT sample (UA771) at the 1974 station (Fig. 3). At Station 91-2, where LCT also occurs, peat L7 is an autochthonous, humified *Sphagnum* peat dominated by *S. lenense*, but also includes a few fragments of *Sphagnum magellanicum* and *S. macrophyllum* var. *burinense*. Today *S. lenense* is common at forest tundra and tundra sites, while *S. magellanicum* is typical of peatlands well within treeline (Janssens, 1979). Today *Sphagnum macrophyllum* var. *burinense* grows only in maritime Newfoundland (Maass, 1967).

Leaves of larch are abundant in sample 74-1. Rarer are needles of spruce and *Pinus*. The latter represent at least two white pine species, one in the Old World group, *Cembrae* (Fig. 4f), and the other a species in subsection *Eustrobi*, which contains extant North American white pines.

The L7 peat also contained a few seeds of *Sambucus* (elderberry) and the extinct plant *Aracites globosa* (Bennike, 1990; Matthews and Ovenden, 1990). The fossils are exceptionally well preserved, meaning that the plant was probably growing locally at wet openings within the forest.

Insect remains from sample 2-1 at Station 91-2 are similar to those from the 1974 locality, including several types (e.g., Pselaphidae) which now occur well south of interior Alaska plus others not found today anywhere in North America as well as several extinct forms (e.g., *Carabus* cf. *nemoralis* group (Fig. 4h), *Notiophilous* cf. *aeneus*, and the cryptic streamside beetle *Georyssus*). The most unusual of the latter group is the tiny, nearly blind weevil *Otibazo* (Fig. 4g), now found in Japan living in deep forest litter (R. Anderson, personal communication, 1991). *Otibazo* indicates not only a warmer climate than at present but possibly the absence of permafrost.

Thus, the fossils from peats containing LCT clearly support the Late Pliocene date on the tephra. Furthermore, they point to a boreal forest that was quite different from that of the present in its composition both of conifers and other plants and of insects.

Section 91-3 is located some distance from the freshly exposed part of the exposure, creating difficulty in correlation. Nevertheless it is an important locality because of peat L9, which contains both Fortymile tephra and well-preserved fossils. Among the fossils are well-preserved needles of a *Cembrae* type five-needle pine (Fig. 4f). This alone is evidence that Fortymile tephra is pre-Quaternary (Matthews and Ovenden, 1990). But the most significant plant fossils from sample 3-1 (peat L9 in Fig. 3) are exceptionally well-preserved "fruits" of *Epipremnum crassum* (Fig. 4d) and *Aracites globosa. E. crassum* occurs at other late Tertiary sites in the Canadian arctic and subarctic, but rarely are the fossils as well preserved as those from sample 3-1. The plants must have been growing locally, possibly in the same poorly drained habitat as *A. globosa*. Insect fossils from this sample also suggest poorly drained conditions.

Discussion

The Lost Chicken site provides important documentation of the flora, vegetation, and insect fauna of interior Alaska before the onset of global cooling 2.5 myr ago. This cooling eliminated a number of tree and shrub species and created conditions favorable for the development of the type of boreal forest existing today and through much of Quaternary time. For example, pines grew at Lost Chicken 3 myr ago, but by 2 myr, spruce had become the dominant boreal forest tree in NW North America and that dominance has persisted through at least eight interglacials (Schweger, 2001, 2002).

Regional setting

At LC-II, units A through F and all of the organic beds were deposited in a valley-floor setting and represent active channel and floodplain environments of various types, including forest-floor accumulations. The LC-II exposure extends almost to the wind gap at the head of the valley, and it is clear that the Pliocene valley-floor deposits extend through the wind gap, as shown on the geologic map of Foster and Keith (1969). Therefore, when these beds were deposited, the valley of Lost Chicken Creek was receiving discharge from the drainage of Chicken Creek. The absence of similar beds along Chicken Creek below the fluvial terrace remnant of the South Fork suggests that the LC-II beds are associated with the terrace, which is part of an extensive terrace complex that extends all the way to the Yukon and the high-level pre-glacial gravels exposed at Dawson City. The terrace complex may represent the remnants of a broadly alluviated paleovalley system that was active about 3 myr ago and predates the downcutting to present river levels.

Biostratigraphy

A number of extinct plants and insects occur at LC-II (Table 3), a fact in keeping with its 3-myr age. But at least one fossil taxon (*Epipremnum crassum* from 91-3) suggests an age greater than 3 myr. Its last-appearance datum (LAD) in Europe is early Pliocene (Matthews, unpublished report: available from the author). The 91-3 fossils are too well preserved to explain them as rebedded from older units. Thus it is possible that Fortymile tephra is somewhat older than LCT.

Climatic/environmental reconstruction

The northern limit of *Sambucus* (elderberry) is Canadian horticultural zone 3 (Ouellet and Sherk, 1973), where mean July temperature is about the same as at LC-II, but mean January temperature is 10–15° C warmer than at Lost Chicken today (Hare and Hay, 1974). The same type of climatic departure is suggested by the moss *S. macrophyllum*. Evidently, climate was much less continental than now. It may also have been wetter because the prime orographic barriers between LC-II and the Pacific (the Alaska Range, coastal ranges of southern Alaska and the St. Elias Range) were at least 1100 m lower than now (Repenning, 1990).

Insect fossils from LC-II provide yet another line of paleoclimate evidence. Using a semiquantitative method of analysis that has proved valuable for Quaternary beetle assemblages, Elias and Matthews (2002) conclude that summer maximum temperature in east-central Alaska during the early part of the Late Pliocene was slightly lower than at present, but the winter minimum, 2.3° C warmer. Though not as large a deviation as suggested by plants, this finding also portrays a more equable (less continental) climate than now.

A late Pliocene latitudinal climate gradient

Meighen Island in the Canadian Arctic Archipelago (Fig. 1) is nearly 20° north of LC-II and contains plant and insect fossils of the same age (Fyles et al., 1991). Thus, a comparison of the flora and fauna of these two sites (Table 3) contributes information on the climatic and environmental gradient of the time. LC-II is now within the subarctic forest or taiga zone, while Meighen Island is too cold for growth of even the smallest woody plants (Edlund and Alt, 1989). In contrast, 3 myr ago Meighen Island possessed a scrubby conifer forest of the type seen near treeline today (though floristically richer than at present—Matthews and Telka, 1997) and had a much warmer winter and summer climate (Elias and Matthews, 2002). Thus both Meighen Island and LC-II were within a floristically rich boreal forest at the beginning of the Late Pliocene. This implies a boreal zone that was much broader latitudinally than at present (Fig. 1). The latitudinal climate gradient was undoubtedly much lower than today, lower, in fact, than is suggested by other evidence (Kaufman and Brigham-Grette, 1993). According to fossil insects from both sites, there was only 1.2° C difference during the summer months, implying essentially no latitudinal temperature gradient (Elias and Matthews, 2002).

Though the northern boundary of the boreal zone was far north of its present position during the Late Pliocene, the southern limit may have been about where it is today, or at least not north of LC-II. Forests containing southern conifers such as Douglas fir and three-needle-pine did occur as far north as LC-II in early Pliocene time, having been replaced by more typical boreal forest by 3 myr ago (Kunk et al., 1994; White et al., 1997, 1999). Several nonarboreal taxa (*Prunus, Hypericum*, and the *Paliurus* type) are missing from LC-II and Meighen Island (Table 3), but they too were present in east- central Alaska during the early Pliocene (Ager et al., 1994) as well as at early Pliocene sites in the Canadian Arctic (Matthews and Ovenden, 1990).

There are interesting and puzzling floristic differences between LC-II and Meighen Island (Table 3). The presence of *Dryas* (avens) and *Oxyria* (mountain sorrel) and absence of *Sambucus* (elderberry) at Meighen Island (Table 3) is probably due to its being near the regional treeline 3 myr ago. More difficult to explain is why *Thuja occidentalis* (eastern white cedar) was present on Meighen Island and not at LC-II. The absence at LC-II of three other typical Pliocene taxa, *Decodon, Comptonia* and *Physocarpus* is also puzzling. Fossils of all three occur frequently in late Tertiary alluvial deposits of Arctic Canada (Matthews and Ovenden, 1990; Matthews et al., 1990).

In summary, the LC-II fauna and flora, because they are rich in taxa and independently dated to a time represented by at least one other site in northern North America, con-

Table 3
Comparison of floral/faunal elements: Lost Chicken and Meighen Island

Plants	LC-II	Meigh Is.	Arthropods	LC-II	Meigh Is.
Epipremnum crassum†	+	+*	*Carabus* cf. *nemoralis*†	+	+
Aracites globosa†	+	+	*Pterostichus* (*Cryobius*)	+	+
Abies	+	+	*Notiophilous* (narrow int.)	+	−
Larix†	+	?	*Trachypachus* sp.	+	+
Picea	+	+	*Georyssus*†	+	+
Pinus (*Strobus*)†	+	+	*Diacheila matthewsi*†	+	+
Pinus (*Pinus*)	+	+	*Ochthebius*	+	+
Myrica arctogale†	+	+	*Amara* (*Curtinotus*)	−	+
Thuja	−	+	*Otibaso* sp.	+	−
Comptonia†	−	+	*Grypus* sp.	?	+
Tubela†	−	+	*Dryopthorus*	+	−
Oxyria	−	+	weevil Genus A type	+	−
Ranunculaceae	−	+	Notostraca (*Lepiduris*)	−	+
Decodon†	−	+*	*Asaphidion* sp.†	+	−
Physocarpus	−	+	*Pterostichus patruelis* grp.	+	−
Dryas	−	+	*Micropeplus hopkinsi*†	+	−
Sambucus	+	−	*Limnebius*	+	−
Paliurus type†	−	−			
Hypericum	−	−			
Prunus	−	−			

Notes. LC-II = Lost Chicken, Units A-C including L1, L2, L7, L6, L9. Meighen Is. = Fossils from terrestrial sediments in Beaufort Formation on Meighen Island, District of Mackenzie, N.W.T. (Matthews, unpublished report, available from the senior author.
* indicates found only below marine beds, hence older than 3 myr by some unknown amount.
† indicates extinct taxon.

stitute an important datum for documenting late Tertiary environments as well as dating and correlation of other sites that cannot be independently dated.

Acknowledgements

This study is the result of a Cooperative USGS–GSC program for study of late Tertiary climate change in northwestern North America. Were it not for Troy Péwé's early guidance, it is unlikely that LC-II would ever have been recognized as the key exposure that it is. We also thank Alice Telka and Karen McLauchlin-Hamilton for help in isolating fossils and the late Gerald Hanks for allowing us on his mining property. Thomas Ager and another unidentified reviewer provided helpful suggestions. J. Janssens and H. Crum checked some of the moss identifications.

References

Ager, T.A., Matthews, Jr., J.V., Yeend, E., 1994. Pliocene terrace gravels of the ancestral Yukon River near Circle, Alaska: palynology, paleobotany, paleoenvironmental reconstruction and regional correlation. Quaternary International 22–23, 185–206.

Bennike, O., 1990. The Kap Kobenhavn Formation: stratigraphy and palaeobotany of a Plio-Pleistocene sequence in Peary Land, North Greenland. Meddelelser om Greenland 23, 1–85.

Bigazzi, G., Galbraith, R.F., 1999. Point-counting technique for fission-track dating of tephra glass shards, and its relative standard error. Quaternary Research 51, 67–73.

Cande, S.C., Kent, D.V., 1995. Revised calibration of the geomagnetic polarity timescale for the late Cretaceous and Cenozoic. Journal of Geophysical Research 100, 6093–6095.

Edlund, S.A., Alt, B.T., 1989. Regional congruence of vegetation and summer climate patterns in the Queen Elizabeth Islands, Northwest Territories, Canada. Arctic 42, 3–23.

Elias, S.A., Matthews Jr., J.V., 2002. Arctic North American seasonal temperatures from the latest Miocene to Early Pliocene, based on mutual climatic range analysis of fossil beetle assemblages. Canadian Journal of Earth Sciences 39, 911–920.

Foster, H.L., Keith, T.E.C., 1969. Geology along the Taylor Highway, Alaska. U. S. Geological Survey Bulletin 1281, 1–36.

Fyles, J.G., Marincovich, Jr., L., Matthews, Jr., J.V., Barendregt, R., 1991. Unique mollusc find in the Beaufort Formation (Pliocene) on Meighen Island, Arctic Canada, in: *Paper* 91-1B Geological Survey of Canada, pp. 105–112.

Hare, F.K., Hay, J.E., 1974. The climate of Canada and Alaska, in: Bryson, R.A., Hare, F.K. (Eds.), World Survey of Climatology: Climates of North America, vol 11. Elsevier, Amsterdam, pp. 49–134.

Janssens, J.A., (1979). Subfossil Bryophytes from Lost Chicken, Alaska. Unpublished Bryological Report JJ357.

Kaufman, D.S., Brigham-Grette, J., 1993. Aminostratigraphic correlations and paleotemperature implications, Pliocene–Pleistocene high-sea-level deposits, northwestern Alaska. Quaternary Science Reviews 12, 21–33.

Kunk, M.J., Rieck, H., Fouch, T.D., Carter, T.D., 1994. $^{40}Ar/^{39}Ar$ age constraints on Neogene sedimentary beds, Upper Ramparts, Half-Way Pillar and Canyon Village sites, Porcupine River, east central Alaska. Quaternary International 22–23, 31–42.

Maass, W.S.G., 1967. Studies on the taxonomy and distribution of *Sphagnum*. III. Observations on *Sphagnum macrophyllum* in the northern part of its range. The Bryologist 70, 177–192.

Matthews Jr., J.V., 1970a. Quaternary environmental history of interior Alaska: pollen samples from organic colluvium and peats. Arctic and Alpine Research 2, 241–251.

Matthews Jr., J.V., 1970b. Two new species of *Micropeplus* (Staphylinidae: Coleoptera) from the Pliocene of western Alaska with remarks on the evolution of Micropeplinae. Canadian Journal of Zoology 48, 779–788.

Matthews Jr., J.V., Ovenden, L.E., 1990. Late Tertiary plant macrofossils from localities in Arctic/Subarctic North America (Alaska, Yukon and Northwest Territories): a review of the data. Arctic 43, 364–392.

Matthews, J.V., Jr., Telka, A., (1997). Insect fossils from the Yukon, in: Danks, H.V., Downes, J.A., (Eds.), Insects of the Yukon, Biological Survey of Canada (Terrestrial Arthropods), Ottawa, pp. 911–962.

Matthews Jr., J.V., Ovenden, L.E., Fyles, J.G., 1990. Plant and insect fossils from the late Tertiary Beaufort Formation on Prince Patrick Island, N.W.T., in: Harington, C.R. (Ed.), Canada's Missing Dimension: Science and History in the Canadian Arctic Islands, Volume 1. Canadian Museum of Nature, Ottawa, pp. 105–135.

Naeser, N.D., Westgate, J.A., Hughes, O.L., Péwé, T.L., 1982. Fission-track ages of late Cenozoic distal tephra beds in the Yukon Territory and Alaska. Canadian Journal of Earth Sciences 19, 2167–2178.

Ouellet, C.E., Sherk, Lawrence, C., (1973). Map of Plant Hardiness Zones in Canada, Ottawa, Publication 5003. Agriculture Canada.

Porter, L., 1988. Late Pleistocene fauna of Lost Chicken Creek, Alaska. Arctic 41, 303–313.

Preece, S.J., Westgate, J.A., Stemper, B.A., Péwé, T.L., 1999. Tephrochronology of late Cenozoic loess at Fairbanks, central Alaska. Geological Society of America Bulletin 111, 71–90.

Repenning, C.A., 1990. Of mice and ice in the Late Pliocene of North America. Arctic 43, 314–323.

Sandhu, A.S., Westgate, J.A., Alloway, B.V., 1993. Optimizing the isothermal plateau fission track dating method for volcanic glass shards. Nuclear Tracks 21, 479–488.

Schweger, C.E., 2001. The warm periods: Yukon's interglacials, in: Canadian Quaternary Association Meetings, 2001: Program and Abstracts, p. 62.

Schweger, C.E., 2002. Interglacial paleoecology of Yukon, in: AMQUA 2002, American Quaternary Association Program and Abstracts of the 17th Annual Meeting, p. 116.

Staudacher, T.H., Jessberger, E.K., Dominik, B., Kirsten, T., Schaeffer, O.A., 1982. ^{40}Ar–^{39}Ar ages of rocks and glasses from the Nördlinger Ries Crater and the temperature history of impact breccias. Journal of Geophysics 51, 1–11.

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

Westgate, J.A., Walter, R.C., Pearce, G.W., Gorton, M.P., 1985. Distribution, stratigraphy, petrochemistry, and palaeomagnetism of the late Pleistocene Old Crow tephra in Alaska and the Yukon. Can Journal of Earth Sciences 22, 893–906.

Westgate, J.A., Sandhu, A.S., Shane, P., 1997. Fission-track dating, in: Aitken, M., Taylor, R.E. (Eds.), Chronometric and Allied Dating in Archaeology. Plenum, New York, pp. 127–158.

White, J.M., Ager, T.A., Adam, D.P., Leopold, E.B., Liu, G., Jette, H., Schweger, C.E., 1997. An 18 million year record of vegetation and climate change in northwestern Canada and Alaska: tectonic and global climatic correlates. Palaeogeography, Palaeoclimatology, Palaeoecology 130, 293–306.

White, J.M., Ager, T.A., Adam, D.P., Leopold, E.B., Liu, G., Jette, H., Schweger, C.E., 1999. Neogene and Quaternary Quantitative Palynostratigraphy and Paleoclimatology from Sections in Yukon and Adjacent Northwest Territories and Alaska, Bulletin 543, Geological Survey of Canada.