Géographie physique et Quaternaire

Evidence for a hardwater radiocarbon dating effect, Wonder Lake, Denali national park and preserve, Alaska, U.S.A.

Indication de l’effet de l’eau carbonatée sur la datation au radiocarbone, au Wonder Lake (Denali National Park and Preserve, Alaska, U.S.A.).

Jonathan K. Child and Al Werner

Volume 53, Number 3, 1999

URI: https://id.erudit.org/iderudit/004780ar
DOI: https://doi.org/10.7202/004780ar

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 review

Child, J. K. & Werner, A. (1999). Review of [Evidence for a hardwater radiocarbon dating effect, Wonder Lake, Denali national park and preserve, Alaska, U.S.A.] *Géographie physique et Quaternaire*, *53*(3), 407–411. https://doi.org/10.7202/004780ar

Article abstract

Anderson et al. (1994) present a late Pleistocene/Holocene pollen record for lacustrine sediment cores retrieved from the north end of Wonder Lake, Denali National Park and Preserve, Alaska. Bulk radiocarbon age estimates obtained during their study suggest that either a *Picea* refugium persisted in the foothills of the north Alaska Range near Wonder Lake during the Late Wisconsinan, or that bulk radiocarbon age estimates are inaccurate. Subsequent cores recovered from Wonder Lake (and a near-by kettle pond) have been correlated to the Anderson *et al.* core and age dated using Atomic Mass Spectrometry (AMS) radiocarbon age estimates. AMS radiocarbon ages suggest that bulk radiocarbon ages from Anderson *et al.* (1994) are affected by hardwater conditions in Wonder Lake causing them to appear greater than 2000 ^{14}C years too old. The corrected core chronology is consistent with documented regional vegetation changes during the glacial/interglacial transition and does not require a local Picea refugium in the Wonder Lake area during the Late Wisconsinan.

Géographie physique et Quaternaire, 1999, vol. 53, n° 3, p. 407-411, 2 fig., 1 tabl.

EVIDENCE FOR A HARDWATER RADIOCARBON DATING EFFECT, WONDER LAKE, DENALI NATIONAL PARK AND PRESERVE, ALASKA, U.S.A.

Jonathan K. CHILD* and Al WERNER**, respectively Department of Geosciences, University of Massachusetts, Amherst, Massachusetts 01003, U.S.A., and Department of Geology and Geography, Mount Holyoke College, S. Hadley, Massachusetts 01075 U.S.A.

ABSTRACT Anderson *et al.* (1994) present a late Pleistocene/Holocene pollen record for lacustrine sediment cores retrieved from the north end of Wonder Lake, Denali National Park and Preserve, Alaska. Bulk radiocarbon age estimates obtained during their study suggest that either a *Picea* refugium persisted in the foothills of the north Alaska Range near Wonder Lake during the Late Wisconsinan, or that bulk radiocarbon age estimates are inaccurate. Subsequent cores recovered from Wonder Lake (and a near-by kettle pond) have been correlated to the Anderson *et al.* core and age dated using Atomic Mass Spectrometry (AMS) radiocarbon age estimates. AMS radiocarbon ages suggest that bulk radiocarbon ages from Anderson *et al.* (1994) are affected by hardwater conditions in Wonder Lake causing them to appear greater than 2000 ^{14}C years too old. The corrected core chronology is consistent with documented regional vegetation changes during the glacial/interglacial transition and does not require a local *Picea* refugium in the Wonder Lake area during the Late Wisconsinan.

RÉSUMÉ *Indication de l'effet de l'eau carbonatée sur la datation au radiocarbone, au Wonder Lake (Denali National Park and Preserve, Alaska, U.S.A.).* Anderson *et al.* (1994) ont présenté l'inventaire pollinique du Pléistocène supérieur et de l'Holocène de la partie nord du Wonder Lake, à partir de carottes de sédiments lacustres. Les estimations des datations au radiocarbone obtenues au cours de leur étude laisse penser soit qu'un refuge de *Picea* a subsisté dans les contreforts du nord de l'Alaska Range, près du Wonder Lake au cours du Wisconsinien supérieur, soit que leurs estimations sont fausses. Des carottes recueillies par la suite au Wonder Lake (et au Sneaker Pond, un kettle avoisinant) datées par spectométrie de masse ont été corrélées à la carotte de Anderson *et al.* et à l'âge obtenu. Les datations au radiocarbone calculées par spectométrie de masse indiquent que les datations obtenues par Anderson *et al.* (1994) ont été influencées par la présence d'eau carbonatée dans le Wonder Lake, qui leur donne un âge apparent de 2000 ans ^{14}C plus vieux. La chronologie corrigée de la carotte concorde avec les changements dans la végétation généralement rapportés au cours de la transition glaciaire/interglaciaire et ne requiert pas l'existence d'un refuge de *Picea* dans la région du Wonder Lake au cours du Wisconsinien supérieur.

INTRODUCTION

Wonder lake (63°28'N, 150°52'W, 605 m altitude) occupies a narrow, north-south trending valley in the northern foothills of the Alaska Range about 45 km north of Mount McKinley (Fig. 1). The Wonder Lake valley was innundated repeatedly by the Muldrow Glacier during the Late Wisconsinan (Werner, 1982; Ten Brink and Waythomas, 1985). As such, Wonder Lake provides a unique setting for the study of Late Wisconsinan and early Holocene environmental change.

Anderson *et al.* (1994) published a pollen record from Wonder Lake indicating that the Wonder Lake valley was a treeless environment vegetated by *Salix* shrubs and herbs at the end of the Late Wisconsinan. Bulk radiocarbon (^{14}C) age determinations from their study suggests that *Betula* shrubs arrived in the Wonder Lake area by *ca.* 13,500 ^{14}C yr BP and remained the dominant taxa until approximately 11,000 ^{14}C yr BP. Bulk ^{14}C age estimates place the first appearance of *Picea* at approximately 11,300 ^{14}C yr BP and document a sharp increase in *Picea* abundance just prior to 7000 ^{14}C yr BP.

The 11,300 ^{14}C yr BP age estimate for the postglacial appearance of *Picea* in the Wonder Lake core stratigraphy is curious because the well documented *Picea* migration from northwestern Canada into eastern Alaska (*e.g.* Ten Mile Lake, 70 Mile Lake, and Tangle Lake) is estimated at 9000-9500 ^{14}C yr BP (Anderson *et al.*, 1994; Ager and Brubaker, 1985) and at 7500 ^{14}C yr BP in the Nenana River valley (145 km east of Wonder Lake; Ager and Brubaker, 1985). Either the early *Picea* appearance (in Wonder Lake) represents expansion from a local Late Wisconsinan refugium or the associated bulk radiocarbon core chronology is inaccurate (Anderson *et al.*, 1994).

Two factors could be responsible for anomalously old bulk radiocarbon age determinations in Wonder Lake; (1) radiometrically "dead" carbon (*e.g.* coal) contamination derived from local bedrock and/or (2) hardwater conditions in

---

Manuscrit reçu le 12 février 1999 ; manuscrit révisé accepté le 25 mai 1999

* E-mail address: jchild@fando.com
** E-mail address: awerner@mtholyoke.edu

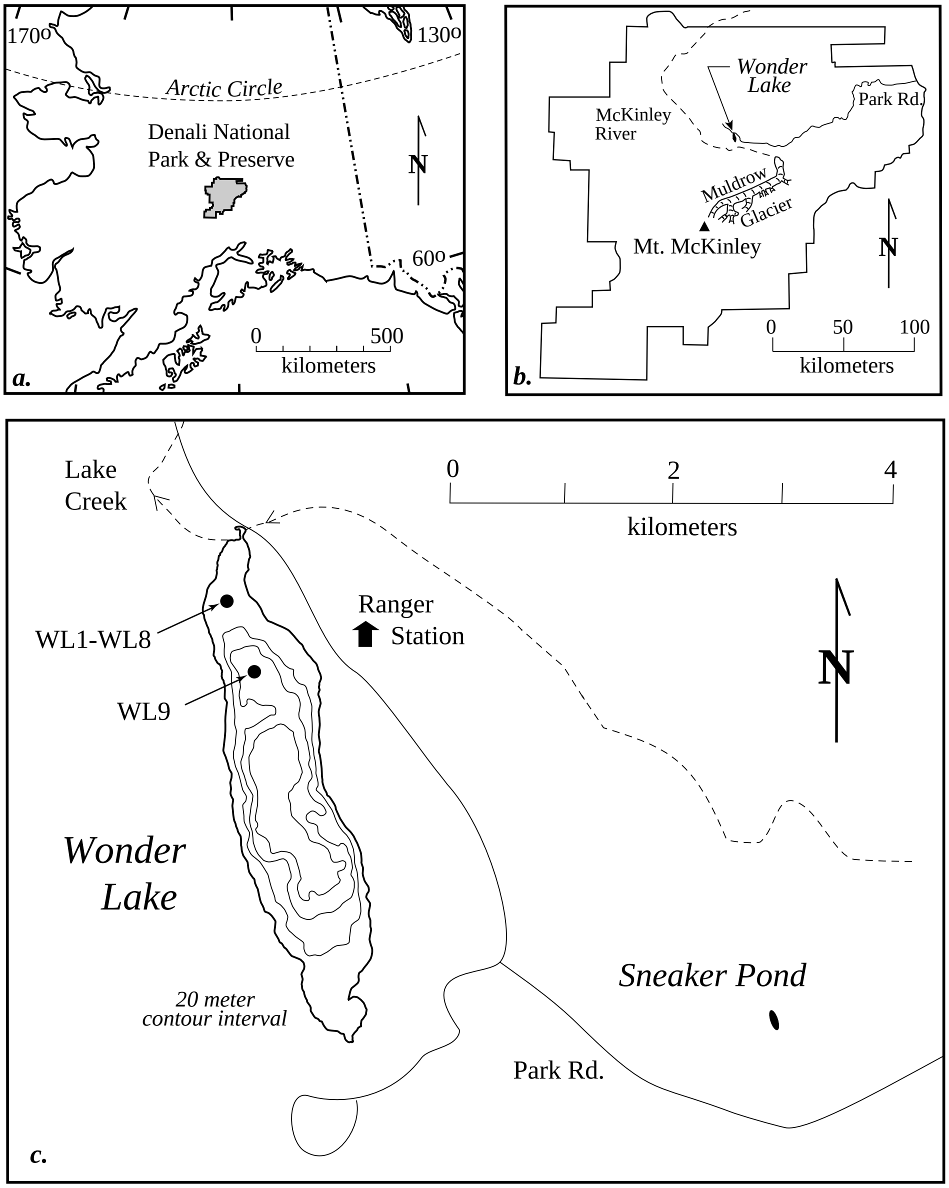

FIGURE 1. Location Map: a) Central Alaska regional map showing the location of Denali National Park and Preserve. b) Denali National Park and Preserve showing the location of Wonder Lake, Muldrow Glacier, and Mount McKinley. c) Local map showing the location of Wonder Lake relative to Sneaker Pond and the location of cores mentioned in the text.

Cartes de localisation : a) localisation du Denali National Park and Preserve, au centre de l'Alaska ; b) localisaion du Wonder Lake, du glacier de Muldrow et du mont McKinley, au Denali National Park and Preserve ; c) emplacement du Wonder Lake par rapport au Sneaker Pond (kettle) et des lieux de forage.

the lake resulting from carbonate dissolution. Coal-bearing units have not been mapped in the McKinley River area (Reed, 1961) and detrital coal fragments have not been observed in washed and sieved sediment samples from Wonder Lake cores. Potential carbonate sources, however, include carbonate-rich facies of the Birch Creek Schist underlying the Wonder Lake basin and glacial drift in the Wonder Lake catchment containing detrital carbonate eroded from carbonate-bearing sedimentary rocks underlying the Muldrow Glacier and its tributaries (Reed, 1961; Gilbert, 1979).

Evidence suggesting the influence of carbonate on the chemistry of Wonder Lake is provided by LaPerriere and Casper (1976) who reported that surface water samples from Wonder Lake had a pH of 7.8 and an alkalinity ranging between 70 to 75 mg/l ($CaCO_3$ equivalent). The presence of "dead" carbon in the waters of Wonder Lake would create a $^{14}C/^{12}C$ ratio in disequilibrium with the atmospheric carbon reservoir (*i.e.* reduced ^{14}C). Primary producers and aquatic herbivores living in Wonder Lake theoretically would incorporate the anomalous $^{14}C/^{12}C$ ratios resulting in ^{14}C age estimates that are older than their actual stratigraphic age.

Cores recovered from Wonder Lake contain an abundance of aquatic invertebrate remains (*e.g. Cladocera ephippia* and midge head capsules; Scott Elias and John Smol pers. comm.). The abundance (70-80 % of organic matter present) of this material in the core sediment suggests that bulk sediment ^{14}C ages may be strongly influenced by the apparent age of aquatic invertebrates in the sediment. If hardwater conditions are present in Wonder Lake, AMS ^{14}C ages from isolated aquatic invertebrate remains should yield ages similar to the bulk sediment ages of Anderson *et al.* (1994), and both should be consistently older than AMS ^{14}C ages from terrestrial plant remains (*e.g.* tundra moss, leaves and seeds) collected from the same stratigraphic positions.

METHODS

The Anderson *et al.* (1994) pollen cores, ranging in length from 292-316 cm, were recovered in 11.3-11.6 m water depth on the shallow platform at the north end of Wonder Lake. Physical core descriptions note a felsic tephra at 82 cm and the presence of sand and gravel, near the base of the longest recovered core (P. Anderson, personal communication, 1990). Eight lacustrine sediment cores (Wonder Lake cores WL1 through WL8) ranging in length from 222-318 cm were recovered in 11.6-11.9 m water depth from the north end of Wonder Lake (Fig. 1c) in roughly the same location as the Anderson *et al.* cores. Additional cores were retrieved from a small kettle pond (informally known as Sneaker Pond) located 1 km to the east of Wonder Lake and from a deep basin within Wonder Lake (WL9; Fig. 1c) for stratigraphic comparison. Cores were recovered using a modified Nesje corer (Nesje, 1992).

CORE CORRELATION

The occurrence of two prominent felsic tephra units (FT-1 and FT-2) in all of the recovered cores allows confident stratigraphic correlation and provides useful age control against which the radiocarbon ages can be evaluated. Correlation of the Wonder lake cores with the Sneaker Pond core was facilitated by magnetic susceptibility (MS) data which effectively identify the iron-bearing ash units. MS measurements of lacustrine cores were acquired with a Sapphire Instruments SI-2 MS system at 3-cm intervals prior to splitting using a 110-mm diameter inductance coil. MS data are not available for the Anderson *et al.* (1994) cores.

Loss on ignition (LOI) data, used as a proxy for organic matter content, were obtained during this study and the Anderson *et al.* (1994) study by sample combustion at 550 °C for two hours after drying at 90 °C. LOI data and physical core descriptions allow confident correlation of the Anderson *et al.* (1994) core stratigraphy with Wonder Lake cores obtained in this study (Fig. 2).

AMS RADIOCARBON SAMPLE PREPARATION

Potential hardwater effects on ^{14}C ages from Wonder Lake sediment were assessed by comparing AMS ^{14}C age estimates from aquatic invertebrate remains in Wonder Lake core WL8 with stratigraphically equivalent AMS ^{14}C age estimates from terrestrial organic matter in Sneaker Pond core SP16 and Wonder Lake core WL9. AMS ^{14}C samples of terrestrial organic matter from the later two cores were used because these cores contain significantly higher concentrations of plant macrofossils than the WL8 core. To acquire sufficient aquatic invertebrate remains, sediment samples from three adjacent Wonder Lake cores WL4, WL6 and WL8 (recovered within a 20 m radius of each other) were combined. At all ^{14}C sampling locations, sediment was collected from a discrete 1-1.5 cm interval immediately above or below the felsic tephra units (Fig. 2).

Initially, Wonder Lake sediment samples were dispersed in distilled water, mechanically disaggregated with a sonic dismembrator, and washed on a 90-micron sieve to remove fine silt and clay. However, this process tended to destroy the physical integrity of organic matter in the sample making it difficult to isolate organic matter for AMS ^{14}C dating. Subsequently, a chemical disaggregation technique outlined in Jones *et al.* (1993) was adopted. This technique employs a dilute (10 %) NaOH solution to disaggregate sediment samples without compromising the integrity of organic matter. NaOH pre-treated samples were washed on a 45-micron sieve with distilled water to remove clastic sediment.

AMS samples were hand-picked from pre-treated sediment samples under a microscope in a positive air-flow hood. The selected samples were inspected for contamination and submitted to the Laboratory for Accelerator Radiocarbon Research (LARR) at the Institute of Arctic and Alpine Research (INSTAAR), University of Colorado, Boulder, for ^{14}C sample target preparation. Sample targets were sent by LARR to the Center for Accelerator Mass Spectrometry (CAMS) at the Lawrence Livermore National Laboratory for AMS radiocarbon age determinations.

RESULTS

CORE CORRELATIONS

LOI results from the Anderson *et al.* (1994) core and core WL8 contain similar down-core trends and characteristic features (Fig. 2). For example, the LOI minimum (1.1 %) near the base of the Anderson *et al.* (1994) core is similar to the LOI minimum (1.7 %) between 283 and 287 cm in core WL8. A felsic tephra is identified in both cores at approximately 80 cm depth and a second tephra identified in WL8 is likely associated with the decrease in LOI at 150 cm in the Anderson *et al.* core (although a tephra unit was not described). As shown in Figure 2, the two tephras (FT-1 and FT-2) appear as distinct peaks in magnetic susceptibility allowing for confident correlation of core stratigraphies and inter-basin comparison of stratigraphically equivalent radiocarbon age estimates.

RADIOCARBON AGE ESTIMATES

Bulk radiocarbon ages of Anderson *et al.* (1994) are compared with AMS ^{14}C age determinations from aquatic invertebrate remains and terrestrial plant fragments above and below the two tephra units (Fig. 2). Radiocarbon dating results show a strong similarity between Wonder Lake aquatic invertebrate AMS ages and the Anderson *et al.* (1994) bulk ^{14}C ages. Furthermore, these ages appear >2000 ^{14}C years older than stratigraphically equivalent AMS ^{14}C age estimates obtained from plant macrofossils in WL9 and Sneaker Pond cores (Table I).

DISCUSSION

The similarity between the bulk radiocarbon ages of Anderson *et al.* and the AMS ages obtained from aquatic

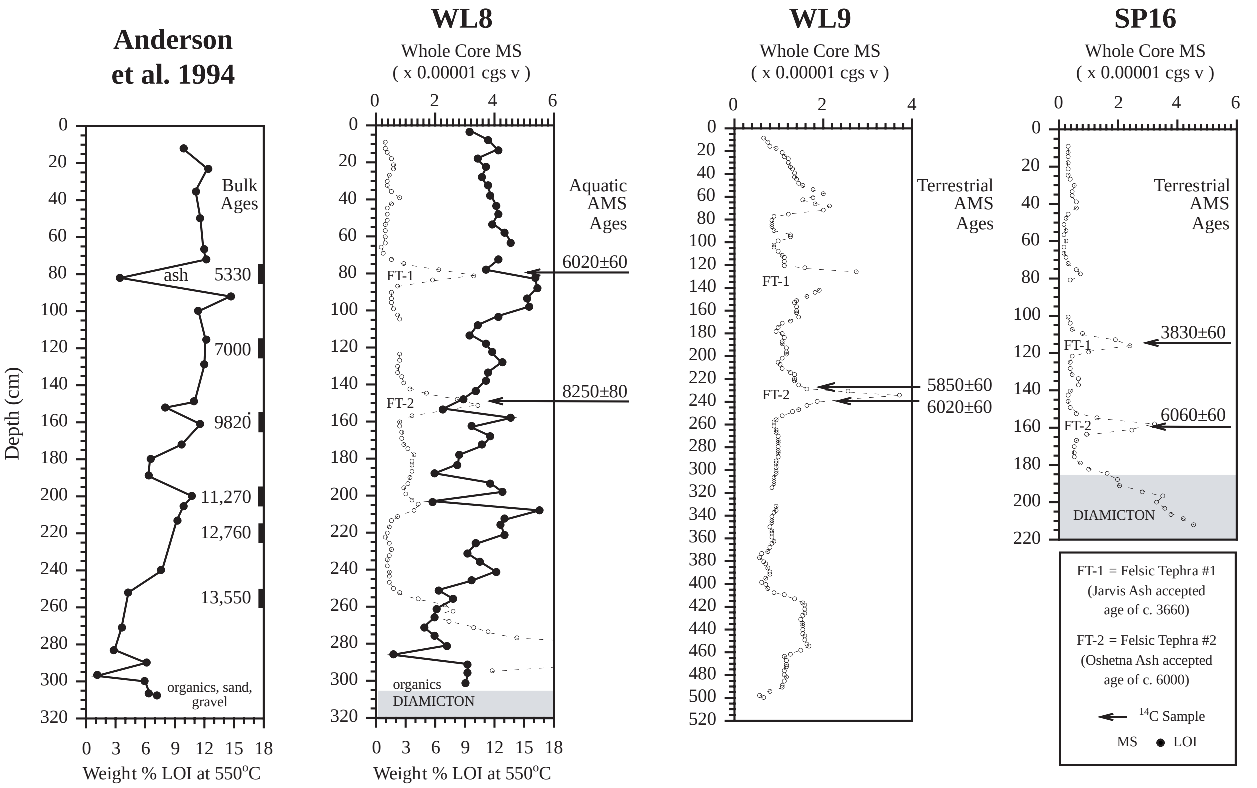

FIGURE 2. Correlation of Cores: Loss on ignition (LOI), magnetic susceptibility (MS) and radiocarbon age data for Wonder Lake and Sneaker Pond cores mentioned in the text. Anderson *et al.* bulk radiocarbon ages and LOI data from Anderson *et al.* (1994). MS peaks associated with felsic tephras FT-1 and FT-2 in cores WL8, WL9, and SP16 are identified.

Corrélation entre les carottes. Données sur la perte au feu (LOI), la susceptibilité magnétique (MS) et les datations au radiocarbone de Wonder Lake et de Sneaker Pond. Datations au radiocarbone et données sur la perte au feu de Anderson et al. *(1994) ; identification de pics de susceptibilité magnétique associés aux tephras FT-1 et FT-2 dans les carottes WL8, WL9 et SP16.*

TABLE I

Chronologic control

Sample identification	Sample description	Depth in core (cm)	Radiocarbon age significance	Radiocarbon age (^{14}C yr BP)	Laboratory identification(3)
WL8A-80-81(1)	aquatic invertebrates	80-81	FT-1 maximum age(4)	6020 ± 60	CAMS-12287
SP16B-23-24	plant fragments	114-115	FT-1 maximum age(4)	3830 ± 60	CAMS-12291
WL8B1-34-35(2)	aquatic invertebrates	149-150	FT-2 minimum age(5)	8250 ± 80	CAMS-12290
SP16B-67-68	plant fragments	158-159	FT-2 maximum age(5)	6060 ± 60	CAMS-12292
WL9B2-20-24	moss, leaf fragments	222.5-226.5	FT-2 minimum age(5)	5850 ± 60	CAMS-15637
WL9B2-36-42	wood, moss, leaf fragments	238.5-244.5	FT-2 maximum age(5)	6020 ± 60	CAMS-15642

(1) Sample WL8A-80-81 includes aquatic invertebrate remains from sample WL4B-19-20 (81-82 cm depth in core WL4) and from sample WL6B1-31-32.5 (81-82.5 cm depth in core WL6).

(2) Sample WL8B1-34-35 inlcudes aquatic invertebrate remains from sample WL4C1-42.5-43.5 (149.5-150.5 cm depth in core WL4) and from sample WL6B1-94.5-95.5 (144.5-145.5 cm depth in core WL6).

(3) AMS radiocarbon age determinations at the Center for Accelerator Mass Spectrometry (CAMS) at the Lawrence Livermore National Laboratory (LLNL).

(4) FT-1 identified as Jarvis Ash with an accepted age of *ca.* 3660 radiocarbon years BP (Child *et al.*, 1998).

(5) FT-2 identified as Oshetna Ash with an accepted age of *ca.* 6000 radiocarbon years BP (Child *et al.*, 1998).

invertebrates picked from our cores indicates that the bulk radiocarbon ages presented by Anderson *et al.* (1994) closely reflect the age of aquatic invertebrate remains. The Wonder Lake ^{14}C ages obtained from aquatic invertebrate remains, however, are significantly older than stratigraphically equivalent AMS ^{14}C ages obtained from plant macrofossils suggesting that hardwater conditions exist in Wonder Lake. Further credibility is added to the WL9 and SP16 AMS radiocarbon ages through the identification of felsic tephra FT-1 as Jarvis Ash (accepted age of *ca.* 3660 ^{14}C yr BP) and felsic tephra FT-2 as Oshetna Ash (accepted age of *ca.* 6000 ^{14}C yr BP; Child, *et al.*,1998). The age determinations from Sneaker Pond of *ca*. 3830 ^{14}C yr BP (Jarvis) and *ca.* 6060 ^{14}C yr BP (Oshetna) and from WL9 of 5850 and 6020 ^{14}C yr BP (bracketing the Oshetna Ash) are consistent with published ages for the tephras and indeed serve to further constrain the timing of their deposition (Child *et al.*, 1998).

Our results indicate the presence of hardwater conditions in Wonder Lake which cause aquatic invertebrate ^{14}C age estimates to be *at least* 2000 years too old. Based on chemical data presented by LaPerriere and Casper (1976) hardwater conditions are likely related to the weathering of carbonate bearing bedrock or glacial drift within the Wonder Lake catchment. Hardwater conditions likely changed through time (as a function of hydrologic conditions and near-surface weathering), and therefore it is unlikely that a 2000 year correction factor can be uniformly applied to all radiocarbon ages presented in the Anderson *et al.* (1994) study. Because of the similarity of the aquatic invertebrate ages and the bulk ages from Anderson *et al.* (1994) coal contamination is not indicated.

CONCLUSION

A comparison of AMS radiocarbon age estimates from plant macrofossils and aquatic invertebrates strongly establishes that the Anderson *et al.* (1994) bulk radiocarbon chronology is affected by hardwater conditions in Wonder Lake causing ^{14}C age estimates to appear at least 2000 ^{14}C years too old. Additional AMS ^{14}C age dating of terrestrial material is needed, however, to accurately date the timing of early Holocene vegetation changes in the Wonder Lake Valley. The corrected AMS radiocarbon chronology presented here indicates that the timing of Late Wisconsinan and Holocene vegetation changes documented by Anderson *et al.* (1994) are broadly consistent with documented regional vegetation changes in the foothills of the north Alaska Range. A local *Picea* refugium was apparently not present in the vicinity of Wonder Lake during the Late Wisconsinan glaciation.

Clearly not all lakes in Alaska have hardwater conditions, and the fact that previously published pollen records are internally consistent suggests that inaccurate chronologies due to hardwater is not a widespread problem. Indeed, it was the fact that the Wonder Lake pollen record stood-out as anomalous that caused Anderson *et al.* (1994) to question their core chronology. Our results, however, illustrate some of the limitations of using bulk radiocarbon ages to constrain lacustrine core chronologies. Not only do bulk samples typically encompass large stratigraphic ages, but they effectively integrate the age of the various organic matter fractions. In contrast, AMS radiocarbon dating of specific fractions of organic matter affords the opportunity to identify sample contamination (dead carbon) and hardwater conditions, and has the added benefit of yielding more precise age estimates.

ACKNOWLEDGEMENTS

This research was sponsored by NSF Grant DPP-9123145 and the National Park Service. Radiocarbon dating was subsidized in part by PALE. A special thanks to Scott Elias and John Smol for their assistance with the identification of organic matter fractions, to Phil Brease and the National Park Service for logistical support, and to Pat Anderson for open communications concerning the radiocarbon chronology and core observations. This publication is PALE publication # 137.

REFERENCES

Ager, T. A. and Brubaker, 1985. Quaternary Palynology and Vegetational History of Alaska, p. 353-384. *In* V. M. Bryant and R. G. Holloway, eds., Pollen Records of Late-Quaternary North American Sediments. American Association of Stratigraphic Palynologists Foundation, Dallas.

Anderson, P. M., Lozhkin, A. V., Eisner, W. R., Kozhevnikova, M. V., Hopkins, D. M., Brubaker, L. B. and Colinvaux, P. A., 1994. Two late Quaternary pollen records from south-central Alaska. Géographie physique et Quaternaire, 48: 131-143.

Béget, J. E., Reger, R. D., Pinney, D., Gillispie, T. and Campbell, K., 1991. Correlation of the Holocene Jarvis Creek, Tangle Lakes, Cantwell, and Hayes Tephras in south-central and central Alaska. Quaternary Research 35: 174-189.

Child, J. K., Béget, J. E. and Werner, A., 1998. Three Holocene tephras identified in lacustrine sediment cores from the Wonder Lake area, Denali National Park and Preserve, Alaska. Arctic and Alpine Research, 30,1: 89-95.

Gilbert, W. G., 1978. A Geologic guide to Mount McKinley National Park. Alaska Natural History Association, Anchorage.

Jones, V. J., Battarbee, R. W. and Hedges, R. M., 1993. The use of chironomid remains for AMS ^{14}C dating of lake sediments. The Holocene, 3: 161-163.

LaPerriere, J. and Casper, L., 1976. Biogeochemistry of deep lakes in the central Alaskan Range: Completion Report. University of Alaska Fairbanks Institute of Water Resources Report IWR-68.

Nesje, A., 1992. A piston corer for lacustrine and marine sediments. Arctic and Alpine Research, 24: 257-259.

Reed, J. C., 1961. Geology of the Mount McKinley Quadrangle, Alaska. U.S. Geological Survey Bulletin, 1108-A: 1-36.

Ten Brink, N. W. and Waythomas, C. F., 1985. Late Wisconsin glacial chronology of the north-central Alaska Range — A regional synthesis and its implications for early human settlements, p.15-32. *In* W. R. Powers, ed., North Alaska Range Early Man Project. National Geographic Society, Washington, D.C.

Werner, A., 1982. Glacial geology of the McKinley River Area, north-central Alaska Range, with an evaluation of various relative age dating techniques. Masters thesis, Southern Illinois University.