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OPEN FILE OF2021-1

MANITOBA RADIOCARBON AGES: UPDATE

Manitoba Geological Survey





Open File OF2021-1

Manitoba radiocarbon ages: update

**by M.S. Gauthier
Manitoba Geological Survey
Winnipeg, 2021**

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Cover illustration: Marine *Hiatella arctica* shells enclosed in sand.

Abstract

This Open File provides the first update on Manitoba radiocarbon ages since 2000. The digital dataset is a compilation of 1371 geologic and archaeologic radiocarbon ages, provided as both conventional radiocarbon ages (^{14}C year BP) and calibrated ages (cal year BP). It includes a determination of anomalous and maybe-anomalous ages that should be discarded or confirmed by the user in future work. This data can be brought into GIS software, and integrated with other data, to further chronological reconstructions in Manitoba.

Résumé

Ce dossier ouvert contient la première mise à jour effectuée depuis 2000 sur les âges déterminés par radiocarbone au Manitoba. Cet ensemble de données numériques est une synthèse de 1 371 âges au radiocarbone se rapportant à la géologie et à l'archéologie. Les données comprennent à la fois les âges au radiocarbone habituels (année ^{14}C avant le présent) et les âges calibrés (année calibrée avant le présent). Des âges anormaux ou possiblement anormaux ont été déterminés et devront être écartés ou confirmés par l'utilisateur lors de prochains travaux. Les données peuvent être intégrées au logiciel SIG avec d'autres données, dans le but de faire avancer les reconstructions chronologiques au Manitoba.

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Introduction

Radiocarbon dating relies on the assumption that organic materials were in equilibrium with the production of ^{14}C in the atmosphere, and that the ^{14}C in the organism has decayed following the death of the organism. Because ^{14}C has a relatively short half-life, radiocarbon dating has a usable range of ~300 to ~50 000 years.

This Open File contains a compilation of radiocarbon samples analyzed at 25 laboratories (Appendix 1, Table 9) between 1950 and 2020. It is both an update and revision to previous compilations (Teller, 1980; Morlan et al., 2000). This database will be updated annually as new data is released or re-assessed.

Methods

This project began with confirmation of data in the existing internal Manitoba Geological Survey (MGS) database used to produce Morlan et al. (2000), which was an update from Teller (1980). Resources used to update the database include internal MGS data, McNeely and Brennan (2005), Martindale et al. (2016), Dalton et al. (2020) and literature searches. Original references for each radiocarbon-age sample have been verified, cited in Tables 4–7 (“REFERENCES” column) of Appendix 1 and written in full in Table 8 of Appendix 1.

Spatial characteristics

The site location of radiocarbon samples is a mix of GPS coordinates (post-2000) and cartographic estimates (pre-2000). During this update, the locations of some samples have been adjusted to better match the original description and/or figure given for that sample. This was achieved using a mixture of ArcMap Basemap imagery, LiDAR (where available; Government of Manitoba, 2020) and SRTM data (U.S. Geological Survey, 2014). Location adjustments were usually within 1 to 5 km. While this is not a significant distance, the corrected locations allow for better correlation to associated geomorphic landforms in a digital working environment (Gauthier and Keller, 2020). The radiocarbon ages from Tables 4–7 of Appendix 1 are included as ArcMap shapefiles in Appendix 2.

Elevations

Efforts were made to verify existing elevation data, and add missing data, using LiDAR (where available; Government

of Manitoba, 2020) and SRTM (U.S. Geological Survey, 2014) digital elevation models. The elevation was not updated for any ‘approximate location’ samples.

Conventional normalized ages

All ages are reported as conventional radiocarbon ages (Stuiver and Polach, 1977). These ages are denoted as radiocarbon years before present (^{14}C BP), where ‘present’ is taken to be 1950. The error is given as a 1 sigma range for most commercial laboratories, and a 2 sigma range for the Geological Survey of Canada (GSC). Conventional radiocarbon ages also include a correction for isotopic fractionation ($^{13}\text{C}/^{12}\text{C}$ ratio, $\delta^{13}\text{C}$; Stuiver and Polach, 1977). This normalization is calculated using a $\delta^{13}\text{C}$ value (Stuiver and Polach, 1977) that is either measured directly by isotope ratio mass spectrometry, or provided as part of the accelerator mass spectrometry (AMS) process. Measured $\delta^{13}\text{C}$ values are provided in Tables 4–7 (“ Del^{13}C ” column) of Appendix 1. AMS-calculated values include machine fractionation and are hence not reported by the laboratories.

Estimating $\delta^{13}\text{C}$

To use historical radiocarbon ages, the user must first ensure that the data was analyzed and presented in a way that is now agreed upon by the international community (Stuiver and Polach, 1977). A problem arises when the $\delta^{13}\text{C}$ was not measured or machine-calculated, as the ages still need to be conventionally corrected (normalized) to $\delta^{13}\text{C} = -25.0\text{‰}$ (based on the Pee Dee Belemnite [PDB] standard).

Older terrestrial samples

Older terrestrial samples can be normalized using the guidance of Stuiver and Polach (1977) and Morlan (1999). Charcoal, wood, plant macrofossils and bulk organic sediment are assumed to have been normalized to a $\delta^{13}\text{C}$ of -25.0‰ , and are hence not corrected. Peat is corrected using an assumed $\delta^{13}\text{C}$ of -27.0‰ with an error of ± 3 . Comparisons with the measured $\delta^{13}\text{C}$ values in the Manitoba dataset show that these values are generally correct (Table 1). The wood in our dataset tends to skew a bit more negative than ‘assumed’, with a mean and median $\delta^{13}\text{C}$ of -26.9‰ . There is also considerable range in the measured $\delta^{13}\text{C}$ value for bulk organic sediments, which includes everything from sandy eolian paleosols to organic lake sediment (gyttja).

Table 1: Measured $\delta^{13}\text{C}$ values for terrestrial samples in Manitoba.

	Peat	Bison bone	Human bone	Ungulate bone	Bulk organic	Charcoal	Wood
	n=28	n=12	n=11	n=4	n=21	n=26	n=51
Min	-32.7	-25.5	-25.0	-22.1	-32.0	-28.1	-30.0
Max	-24.4	-15.0	-19.0	-18.1	-16.1	-20.6	-23.5
Mean	-27.5	-18.4	-21.4	-19.9	-24.8	-24.3	-26.9
Median	-27.1	-18.6	-21.0	-19.7	-25.5	-24.2	-26.9
Standard deviation	2.2	3.0	1.9	1.8	4.5	1.4	1.5

Older marine samples

At the GSC laboratory, marine shell ages were unconventionally corrected to $\delta^{13}\text{C} = 0.0\text{‰}$ PDB instead of $\delta^{13}\text{C} = -25.0\text{‰}$ prior to 1992. This was corrected when McNeely and Brennan (2005) released corrected ages for marine shells analyzed at the GSC laboratory that had $\delta^{13}\text{C}$ measurements available. The revised shell ages are included herein.

There are 20 marine-shell ages that do not have measured $\delta^{13}\text{C}$ values (seven from the GSC lab, nine from the Brock Geosciences lab, three from Geochron Laboratories and one from the University of Saskatchewan lab). Using the mean/median and standard deviation values provided by McNeely and Brennan (2005) and supported by our own measured $\delta^{13}\text{C}$ values, we have assigned 'assumed' $\delta^{13}\text{C}$ values according to the species of shell (Table 2).

There is also a marine seal bone in the database (S-521), which has been corrected using an assumed $\delta^{13}\text{C}$ value of -15‰ based on the 'marine organisms' estimate of Stuiver and Polach (1977).

Freshwater samples

Wherever possible, terrestrial plant macrofossils, wood and/or charcoal should be sampled for radiocarbon dating instead of aquatic plant macrofossils, or shell-bearing organisms (ostracods, gastropods, pelecypods). There are many times, however, where the less-ideal organic material is the only one available—the database herein contains numerous radiocarbon ages on freshwater shell-bearing organisms, as well as aquatic plant macrofossils.

Correcting for ^{13}C fractionation in freshwater shells is complicated since different micro-environments within the same waterbody can lead to differences in ^{13}C fractionation for different species (Fritz and Poplawski, 1974). This means that a single correction cannot be applied to all freshwater organisms.

For the 1996 Lake Winnipeg project, ostracods were corrected using an assumed $\delta^{13}\text{C}$ of -5.0‰ or -7.0‰ (Todd et al., 2000). Contrastingly, the Canadian Archaeological Radiocarbon Database uses an assumed correction of $\delta^{13}\text{C} = -8.0 \pm 3\text{‰}$ (Martindale et al., 2016). While these numbers are similar and within error, choosing -5‰ instead of -8‰ can lead to a difference of 48 ^{14}C years BP. As such, this is

Table 2: Assumed $\delta^{13}\text{C}$ values for different taxa of marine shells, based on McNeely and Brennan (2005) and supported by measured $\delta^{13}\text{C}$ values for marine shells in Manitoba (Appendix 1, Table 4).

Species	Assumed $\delta^{13}\text{C}$ value
<i>Chlamys islandicus</i>	2.0 ± 1.9
<i>Hiatella arctica</i>	1.2 ± 0.7
<i>Macoma baltica</i>	-1.0 ± 1.53
<i>Mytilus edulis</i>	0.18 ± 1.05
Unidentified	0.85 ± 1.27

another uncertainty to consider when using decay-counting radiocarbon ages calculated using the ostracods samples herein. Two Lake Manitoba ostracod ages in the database have $\delta^{13}\text{C}$ measurements of -3.72 (OS-02658) and -2.67 (OS-02657). Hence, our data suggest that the above ostracod assumed ratios are too negative and that ages using assumed ratios are incorrect.

The Manitoba radiocarbon database includes 93 freshwater shells that have measured $\delta^{13}\text{C}$ values, and 25 freshwater shells that do not. The eleven species are mostly from Lake Winnipeg, and record a wide range of $\delta^{13}\text{C}$. The majority of uncorrected freshwater shell ages in the database are not identified by species. These unknowns, together with the wide range of measured values, mean it is very difficult to assign any sort of approximate $\delta^{13}\text{C}$ value. As such, the 25 uncorrected freshwater shell ages are labelled as anomalous and should not be used.

Bones

Differences in ^{13}C fractionation between plants and grasses are further fractionated up the food chain (Morlan, 1999). Bone collagen from ungulates were corrected using an assumed $\delta^{13}\text{C}$ of $-20.0 \pm 2\text{‰}$. Ages from *Bison* sp. should be considered minimum ages, given their C_4 -plant-rich diet (Morlan, 1999). Bone collagen from *Homo sapiens* are corrected using an assumed $\delta^{13}\text{C}$ of $-19.0 \pm 2\text{‰}$.

Comparisons between the measured $\delta^{13}\text{C}$ values in the Manitoba dataset show that these values are generally correct (Table 1), and our data fits within that compiled by Morlan (1999). The human collagen in our dataset is slightly more negative than the 'assumed', with a mean $\delta^{13}\text{C}$ of -21.4‰ and median of -21.0‰ . The traditional diet in Manitoba was omnivorous, both for terrestrial and aquatic species (Syms, 2018). Though the data are limited, it could mean the four conventional radiocarbon ages on human bone collagen are ~30 to 40 years younger than shown in Tables 4–6 of Appendix 1 (Gak-5447, S-651, S-743, S-1303). In studies where better precision is needed, it is important to ensure that the ^{13}C ratio is measured and not simply estimated. Syms (2018) suggests that this ratio is measured for both bone collagen (protein information) and bone apatite (total diet).

Calibrated ages

To compare radiocarbon ages obtained on terrestrial, freshwater and marine organisms within Manitoba, it is necessary to calibrate the ages. It is important to note that radiocarbon ages do not directly equate with calendar years. This is because radiocarbon concentration in the atmosphere varies through time, due to changes in the production rate (de Vries, 1958). As such, calibrations use independently-dated archives such as tree rings, lacustrine and marine sediments, speleothems and corals (Heaton et al., 2020; Reimer et al., 2020). Calibrated ages are accompanied by complex, sometimes

multimodal, calibrated age probability distributions that may require stratigraphic information to resolve.

All non-anomalous radiocarbon ages herein were converted to calendar ages using the program CALIB 8.2 (Stuiver et al., 2020). Ages from terrestrial samples were converted to calendar years using IntCal20 (Reimer et al., 2020) for the northern hemisphere. The marine mollusks were calibrated separately to remove the reservoir effect from these shells by using the Marine20 database (Heaton et al., 2020), with an average reservoir off-set (ΔR) of 110 ± 65 for Hudson Bay (Coulthard et al., 2010).

The user should note that only the highest-probability age-range is denoted herein ("Cal_BP_2 σ " column), with the probability recorded next to the cal BP age-range in Table 4 of Appendix 1 ("Cal_BP_2 σ _probability" column). Where the probability is less than 1, the user may want to refer to the probability distributions calculated within CALIB 8.2 for alternate age ranges (Stuiver et al., 2020). Calibrated ages are commonly presented in the literature as median ages, with an uncertainty of 1 or 2 sigma (σ). Both the 2 σ age-ranges and the median age are included in Table 4 of Appendix 1. Ages should be presented in publications with all raw data needed for calibration (see Millard, 2014), to be updated by later researchers when new calibration curves are published. Furthermore, the convention is to round the final calculated age to the nearest 10, as the mathematical computations calculate values to a degree that is not precise in reality (Millard, 2014). When using median ages, the user must also include the 2 σ range and the probability (e.g., 8.15 ka cal BP, 7960–8340, 100%).

Discussion

Conventional decay-count vs. AMS methods

This Open File contains radiocarbon ages determined by conventional decay-count (radiometric) methods and by AMS methods. Both decay-count and AMS methods can provide comparable precision. However, decay-count requires three orders of magnitude more carbon than the AMS method. Hence, historical samples submitted for decay-count methods often used bulk sediment samples, bulk assemblages of macrofossils and/or large pieces of wood. Analysis on bulk samples can lead to inaccuracies, as these samples may have been contaminated by reworked (older) detritus from sediments below, overprinted (younger) detritus such as modern rootlets and/or contain different mixtures of materials (e.g., Bayliss and Marshall, 2019). As such, single-specimen radiocarbon samples are considered to provide more accurate results than bulk samples. At sites where organic material has been dated by both conventional and AMS methods, the AMS method is considered more accurate due to single-specimen precision.

Cautions when interpreting ages

The user is reminded that radiocarbon ages are estimates, and should always be considered with regard to other evidence from the site. For both conventional and AMS methods, trace amounts of modern carbon can generate an apparent age that is ultimately incorrect (e.g., Reyes et al., 2020). Reproducibility between (and within) laboratories is also a concern, a problem which seems to increase with older materials (Ward and Clague, 2019). In situations where a hypothesis is based on the result, duplicate radiocarbon ages should be obtained from the same material, and possibly analyzed at different labs (e.g., McMartin et al., 2019). Different pre-treatments may also help to confirm the radiocarbon age (e.g., Bajc et al., 2015). Replicate measurements on different single-specimen samples from the same context or feature can also help (Bayliss and Marshall, 2019). In all cases, other proxies (paleoenvironment, ice-flow dynamics, Heinrich events, other dating methods, cultural context, etc.) should be considered when interpreting a radiocarbon age.

Freshwater reservoir (hard-water) effect

Radiocarbon dating relies on the assumption that organic materials were in equilibrium with the production of ^{14}C in the atmosphere during their lives. Importantly, scientists have learned that organic materials are also affected by inorganic carbon within freshwater environments that overlie both carbonate rocks (Deevey et al., 1954; Andree et al., 1986; MacDonald et al., 1987), and/or lignite, coal and carbonaceous shales (Nambudiri et al., 1980). There may have been different uptake conditions within different lacustrine or fluvial bodies, and within different time periods (Shotton, 1972). Contamination by old-carbon is termed the hard-water effect, and is important in Manitoba because most glacial and postglacial sediments in Manitoba are calcareous (Manitoba Agriculture and Resource Development, 2020). The hard-water effect is also important when interpreting 'terrestrial' radiocarbon ages obtained from bones of species (birds, humans, canines, bear, wolf, etc.) that may have eaten a marine and/or freshwater diet (Syms, 2018). In these cases, $^{15}\text{N}/^{14}\text{N}$ ratios should be analyzed to help determine if fish or other aquatic species were part of the diet—if they were, a freshwater (hard-water) correction is needed (Syms, 2018). The column "Del ^{15}N " has been added to Appendix 1, and it is the intention of the MGS to collect this ratio on all bones and antlers moving forward.

A hard-water correction is typically calculated by comparing the ages of terrestrial and freshwater material collected from the same horizon at the same site. Unfortunately, this calculation exists for only a few places in Manitoba, and mostly for mid-Holocene shell samples. Given these limitations, no hard-water corrections have been made to the data herein. Instead, the notation "FRE?" is added to the conventional and calibrated ages in Table 5 of Appendix 1 (122 ages), acknowledging the need for future correction as the user finds appropriate.

Potential bone samples affected by a freshwater diet (e.g., *Homo sapiens*), and without a paired terrestrial sample, are also included in this table.

Marine reservoir effect

The concentration of carbon isotopes differs between the ocean and the atmosphere, with a ‘reservoir’ in the global oceans that results from trapped old carbon. This reservoir effect results in an apparent radiocarbon age of a marine sample that is different from the true age (when carbon exchange between the organism and the atmosphere would be equal). As such, measured radiocarbon ages from marine samples can’t be directly compared to measured radiocarbon ages from terrestrial samples. Complicating matters, the level of depletion varies due to spatio-temporal differences in the ocean and the atmosphere (Heaton et al., 2020). To account for this, a marine radiocarbon reservoir age (MRA) is applied to marine organisms used in radiocarbon dating (Stuiver et al., 1986; McNeely et al., 2006; Coulthard et al., 2010). The MRA is calculated using the difference between the global mean ocean reservoir correction and the regional reservoir age, termed the regional reservoir offset ($\Delta R(\theta)$; Heaton et al., 2020). $\Delta R(\theta)$ will remain approximately constant through time, assuming that the regional oceanographic characteristics remain (Stuiver et al., 1986; Stuiver and Braziunas, 1993). Herein, we calibrate the marine radiocarbon ages using the mollusc marine regional reservoir offset $\Delta R(\theta)=110 \pm 65$ years for Hudson Bay (Coulthard et al., 2010). The regional mollusc MRA (R_R) was calculated using twelve live-collected shells sampled between 1920 and 1954 (pre-bomb).

A recent study on marine walrus bones has determined a different reservoir offset than that of molluscs (Dyke et al., 2019), which should caution the user against using mollusc-based corrections for marine mammals. The database herein has one single marine mammal age, which for lack of a better correction, has been tentatively calibrated using the mollusc MRA (S-521; Rutherford et al., 1973).

Marine hard-water effect

Marine materials are affected by inorganic carbon within environments that overlie carbonate or calcareous rocks. Open marine water contains marine dissolved inorganic carbon, which generally masks the hard-water effect. The hard-water effect may be a concern in areas with restricted water circulation, areas of considerable mixing between freshwater and marine waters, overlying highly calcareous substrate, and in areas with high abundance of terrestrial organic matter (Douka et al., 2010). Radiocarbon dating of filter-feeding molluscs will result in avoidance of the hard-water effect relative to deposit-feeding molluscs (England et al., 2013). The database herein contains radiocarbon ages for eight different shell taxa, broken down in Table 3. A ninth taxon, *Portlandia arctica* can be found within the anomalous table, given its proven hard-water

Table 3: Marine shell taxa within the Manitoba radiocarbon database, and their feeding behaviours (after McNeely et al., 2006).

Species	Number of samples	Habitat ¹	Feeding ²
<i>Astarte borealis</i>	1	Infaunal	Suspension
<i>Chlamys islandicus</i>	3	Epifaunal	Suspension
<i>Clinocardium ciliatum</i>	1	Infaunal	Suspension
<i>Hiatella arctica</i>	38	Epifaunal	Suspension
<i>Macoma baltica</i>	2	Infaunal	Deposit
<i>Macoma calcarea</i>	10	Infaunal	Deposit
<i>Mya truncata</i>	4	Epifaunal	Suspension
<i>Mytilus edulis</i>	9	Epifaunal	Suspension
Unidentified	21	?	?

¹ Epifauna are organisms that live upon the surface of sediments. Infauna are organisms that live within sediments.

² Suspension feeders (filter feeders) are animals that feed by straining suspended matter from the water. Deposit feeders are animals that feed by obtaining food particles in the sediment.

effects (England et al., 2013). The twelve *Macoma* sp. radiocarbon ages herein are tagged as ‘maybe anomalous’ (Appendix 1, Table 6), because they are deposit feeders and may need a hard-water correction in addition to the MRA correction. Unidentified shells are also classified as ‘maybe anomalous’, given the difficulty of determining feeding behaviour on these ages. Only one site in Manitoba contains radiocarbon ages on bulk samples of both *Hiatella arctica* and *Macoma baltica*. As the *Hiatella arctica* samples (GSC-3367, BGS-791; Nielsen et al., 1986) were collected ~4 m lower than the *Macoma baltica* sample (BGS-797; Morlan et al., 2000), it is impossible to assess a potential hard-water effect—except to note that the upper shells are younger, as expected.

There are very few early Holocene paired terrestrial-marine samples within Hudson Bay, with which to assess a hard-water effect. On Southampton Island, early–mid-Holocene paired terrestrial-marine ages provided a regional marine reservoir age of -630 ± 45 ¹⁴C years (Ross et al., 2012) and a reservoir offset (ΔR) age of 263 ± 48 years. That is similar to the reservoir offset (ΔR) age for Foxe Basin proposed by Coulthard et al. (2010; 310 ± 90), and suggests the modern correction is valid—without the need for a hard-water correction. Contrastingly, on Baffin Island in the eastern Foxe Basin, Vickers et al. (2010) calculated a mean reservoir offset (ΔR) age of 615 ± 20 years for early–mid Holocene terrestrial-marine pairs. Ross et al. (2012) suggested the difference may be due to underlying geology (the hard-water effect), as northern Southampton Island is granitoid while the Baffin Island sites are calcareous. As such, more local data is needed to ascertain the validity of the corrections applied herein over both time and space.

Infinite and near-infinite ages

Very old samples have such low radioactivity that they cannot be distinguished reliably from the background radiation. Different laboratories set different ‘ages’ as the upper

limit, which can vary based on the weight of the material submitted (Pigati et al., 2007); these ages are usually reported as >BP. Regardless of the reported number, the age of these samples was not determined using radiocarbon methods and is interpreted as non-finite (greater than).

As laboratory methods improve over time, the upper boundary of infinite ages has increased. The user is reminded that small amounts of contamination by younger carbon will have large effects near the upper bounds of radiocarbon limits. Contamination can be introduced during burial (diagenetic or modern rootlets), surface weathering, sampling and/or laboratory processing (Pigati et al., 2007). Hence, a lab-accurate age of 48 ka ¹⁴C BP may not be a ‘true’ accurate age for that organism. Contamination is more likely for peat (modern roots) or carbonate shells (recrystallization; Douka et al., 2010), than for wood. Recommendations on the ‘validity’ of near-infinite ages range from ~40 ka (Walker, 2005) to ~35–40 ka (Miller and Andrews, 2019)—though the latter paper lacks a source for such a recommendation. In every case, all available geological and site-specific evidence should be considered when interpreting age results, and other proxies (paleoenvironment, ice-flow dynamics, Heinrich events, other dating methods, etc.) should be incorporated.

Anomalous and maybe-anomalous ages

A number of radiocarbon ages have been identified as anomalous, either by the original author during the course of interpretation, or if the material was bulk organic sediment, lake sediment, or organic mud. The latter are tagged as anomalous given the problems with conventional dating of large mixed samples that may contain older transported detritus and/or younger intruding detritus (e.g., Clayton and Moran, 1982; Grimm et al., 2009; Bayliss and Marshall, 2019). Bulk lake sediment (gyttja) samples also contain nonorganic detritus that contributes to a hard-water effect (see above), which is difficult to correct for given the potential for contamination and re-working. A recent compilation paper by Young et al. (2021) has chosen to reject all bulk lake/soil samples during their analysis—and we advise the same. These rejected samples are retained in the database, and clearly marked ‘yes’ under the column “ANOMALOUS” (260 samples; Appendix 1, Table 7). The notation “A” is added to the conventional age, to further remind the user that the age is likely not valid. The specific reason why each sample was determined to be anomalous is written under column “ANOMALOUS_WHY”.

Additional samples are tagged as ‘maybe’ anomalous. This includes stratigraphically inversed (e.g., older above younger) ages and ages near the upper boundaries for radiocarbon dating (>40 ka). Near-finite ages should be confirmed through stratigraphy (including till composition) and re-dating, since they are near the boundary between interstadial MIS 3 (29–57 cal ka BP; Lisiecki and Raymo, 2005), and MIS 5 (infinite). The notation “M” is added to the conventional age, to further

remind the user that the age may not be valid (119 samples; Appendix 1, Table 6). The specific reason why each sample was determined to be maybe anomalous is written under column “ANOMALOUS_WHY”.

Macrofossil reports

A number of samples were submitted to A. Telka for macrofossil identification. Most of these samples are associated with a macrofossil report, which includes information on different types of plant and animal macrofossils contained within the submitted sediment. These reports are identified with a number under the column “REPORT” and the actual report information is embedded within the “COMMENTS” column of Appendix 1, Tables 4–7.

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