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Short Paper

Radiocarbon ages of terrestrial gastropods extend duration of ice-free conditions at the Two Creeks forest bed, Wisconsin, USA

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ABSTRACT

Analysis of terrestrial gastropods that underlie the late Pleistocene Two Creeks forest bed (~13,800–13,500 cal yr BP) in eastern Wisconsin, USA provides evidence for a mixed tundra-taiga environment prior to formation of the taiga forest bed. Ten new AMS ^{14}C analyses on terrestrial gastropod shells indicate the mixed tundra-taiga environment persisted from ~14,500 to 13,900 cal yr BP. The Twocreekan climatic substage, representing ice-free conditions on the shore of Lake Michigan, therefore began near the onset of peak warming conditions during the Bølling–Allerød interstadial and lasted ~1000 yr, nearly 600 yr longer than previously thought. These results provide important data for understanding the response of continental ice sheets to global climate forcing and demonstrate the potential of using terrestrial gastropod fossils for both environmental reconstruction and age control in late Quaternary sediments.

The Two Creeks type locality, situated on the western shore of Lake Michigan in Wisconsin, USA contains one of the most famous late Pleistocene glacial/interstadial sequences in North America. First studied by J.S. Goldthwait in 1907, the exposure consists of a glacial diamicton overlain by lacustrine silts and sands and capped by the Two Creeks forest bed. The forest bed, which contains stumps and other remains of spruce trees (*Picea mariana* and *Picea glauca*), is itself overlain by lacustrine and glacial deposits (Fig. 1; Black, 1970). Previous ^{14}C dating and counting of growth rings from buried logs and stumps indicated a calibrated age range of ~13,840–13,620 cal yr BP for the forest bed and a minimum lifespan for the forest of ~230 to 250 yr (Broecker and Farrand, 1963; Kaiser, 1994). Subsequent work by Panyushkina and Leavitt (2007) and Leavitt et al. (2007) indicated a minimum lifespan of 329 yr and an age range of 13,760–13,530 cal yr BP. Constraining the age and duration of ice-free conditions at the Two Creeks locality is important for understanding the response of the Laurentide Ice Sheet to global climate forcing (Lowell, 2000). The existing age control suggests that the Twocreekan interval began ~1000 yr after the beginning of the Bølling–Allerød interstadial (14,740 ± 60; Lemieux-Dudon et al., 2010) and was of relatively short duration (~330 yr).

To reconstruct environmental conditions prior to formation of the forest bed and to determine the duration of ice-free conditions, we collected gastropod shells from just below the Two Creeks forest bed at the Two Creeks type locality (Fig. 1). Approximately 10 liters of the top (upper 3 cm) of the gray silt unit was collected, soaked in water, and sieved to isolate gastropod shells. Shells were classified and separated based on shell morphology. The terrestrial gastropod fauna was compared to 171 modern stations from Alaska, Manitoba, and Quebec (Nekola, 2010) through global non-metric multidimensional scaling (Minchin, 1987). Pairwise dissimilarity values were calculated using the Czekanowski index (Faith et al., 1987) on site presence–absence data. NMDS in two dimensions was then performed on 50 initial random starting configurations, with 200 maximum iterations, a stress-ratio stopping value of 0.9999, and a small-stress stopping value of 0.01. Unique solutions were identified using a Procrustes transformation, with the number of runs falling onto each solution being enumerated. The modal solution was identified and used to generate the ordination diagram. Terrestrial gastropod shells were processed for AMS ^{14}C dating at Miami University using standard methods (Rech et al., 2011).

The top of the gray silt unit contains aquatic and terrestrial gastropods representing the transition from an aquatic to terrestrial environment. Terrestrial gastropod shells include at least twelve different taxa (*Columella columella* [48 shells], *Columella simplex* [2], *Discus cronkhitei* [71], *Euconulus fulvus* [23], *Pupilla muscorum* [17],

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Succineidae spp. [93], *Vallonia gracilicosta* [4], *Vertigo cristata* [1], *Vertigo elatior* [135], *Vertigo hannai* [9], *Vertigo modesta arctica* [8], *Vertigo oughtoni* [14]). Comparison of these taxa with modern assemblages collected throughout North America suggests a mixed tundra-taiga environment, although the fossil assemblage does not match directly that of any modern locality (Fig. 2). Assuming that these different taxa lived contemporaneously, the closest modern analogs to the Two Creeks fauna are found in 1) a lowland tundra and tamarack-spruce forest in Churchill, Manitoba (*C. columella*, *E. fulvus*, *Pupilla* sp., Succineidae spp., *V. elatior*, *V. hannai*, *V. modesta*, *V. oughtoni*); 2) a transitional tundra-taiga site along the St. Lawrence River in eastern Quebec (*D. cronkhitei*, *C. columella*, *E. fulvus*, *Pupilla* sp., Succineidae spp., *V. gracilicosta*, *V. elatior*, *V. modesta*); 3) a taiga site near Anchorage Alaska, (*D. cronkhitei*, *E. fulvus*, Succineidae spp., *V. modesta*); and 4) a boreal grassland-aspen forest on steep, south-facing slopes in central Alaska (*D. cronkhitei*, *E. fulvus*, Succineidae spp., *V. gracilicosta*) (Fig. 2). Alternatively, the faunal assemblage may represent a transition from tundra to taiga environment if individual specimens are not contemporaneous.

To better constrain the duration of ice-free conditions, we dated ten aliquots of shell material of five different taxa (*D. cronkhitei*, *E. fulvus*, *P. muscorum*, *V. elatior*, Succineidae) by AMS ^{14}C. Radiocarbon ages ranged from 12,390 ± 70 to 12,090 ± 90 ^{14}C yr BP, representing a calibrated age range from 14,520 ± 440 to 13,950 ± 180 cal yr BP (Table 1; Fig. 3). Although terrestrial gastropod shells have long been avoided for radiocarbon dating due to their potential for incorporating ^{14}C-deficient carbon from limestone during shell mineralization (Goodfriend and Stipp, 1983), many terrestrial gastropod taxa in North America incorporate negligible amounts of old carbon into their shells even when living in environments where carbonate rocks are abundant (Pigati et al., 2010). Shells of these taxa, therefore, should yield reliable ^{14}C ages as long as they act as closed systems with respect to carbon over geologic time (Rech et al., 2011). Our data appear to support this hypothesis for several reasons, including 1) the gastropod shell ages (14,520–13,950 cal yr BP) from just beneath the Two Creeks forest bed fall directly prior to the published ages of the forest wood (~13,800–13,500 cal yr BP), 2) the gastropod fauna represents a different paleo-environment from the overlying forest bed, and 3) the ^{14}C ages of gastropod shells cluster tightly between 12,390 ± 70 and 12,090 ± 90 ^{14}C yr BP, which is unlikely if these different taxa contained variable amounts of old carbon.

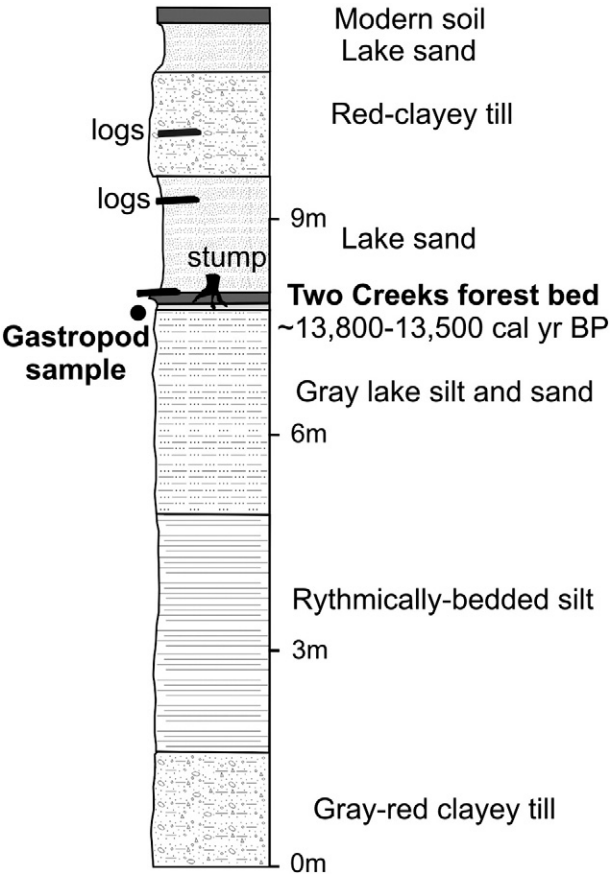

Figure 1. Stratigraphic section of Two Creeks type locality (Black, 1970) and location of terrestrial gastropod sample.

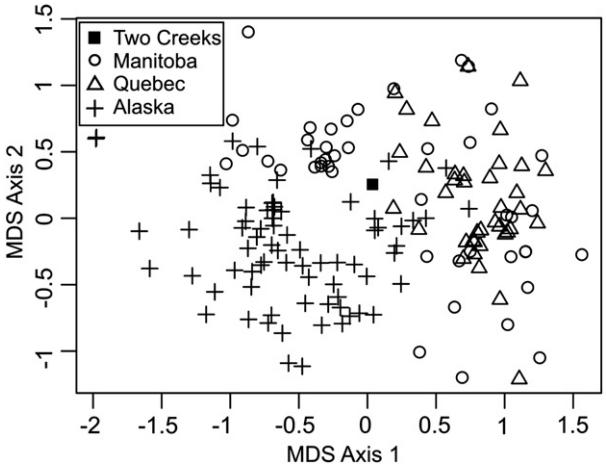

Figure 2. Comparison of the Two Creeks terrestrial gastropod fauna with modern North American tundra-taiga faunas from Manitoba, Quebec, and Alaska using global, non-metric multidimensional scaling. Output was scaled in half-change units, so that an interpoint distance of 1.0 corresponds to a 50% turnover in species composition.

Our analyses of terrestrial gastropods from just below the late Pleistocene Two Creeks forest bed indicate that a mixed tundra-taiga environment existed prior to the forest bed, representing the most recent tundra environment in the Great Lakes region. Moreover, the radiocarbon ages of these shells indicate that the Twocreekan climatic substage, representing ice-free conditions on the shore of Lake Michigan, began just after the onset of the Bølling–Allerød interstadial (14,740 ± 60; Lemieux-Dudon et al., 2010) and lasted ~1000 yr until ~13,500 ka, nearly 600 yr longer than previously thought.

This new understanding of the environment and age of the Twocreekan climatic substage may help explain several aspects of regional stratigraphy. For example, the Valders interstadial deposit southeast of the Two Creeks locality represents a tundra environment that existed prior to the deposition of a red-clayey till, similar to the till overlying the Two Creeks forest bed (Maher and Mickelson, 1996; Maher et al., 1998; Mickelson et al., 2007). However, based on the presence of tundra flora and an assumed radiocarbon age of 12,200 ^{14}C yr, Maher et al. (1998) concluded that this tundra environment represented an interstadial event prior to the Twocreekan. The terrestrial gastropod data presented here may indicate that these interstadial events were contemporaneous. The extended duration of the Twocreekan as indicated by the gastropod shells may also explain the broad range of ^{14}C ages from the Cheboygen bryophyte bed, which was also interpreted to be contemporaneous with the Two Creeks forest bed (Larson et al., 1994).