The Potential for an Independent Source of Younger Dryas Tree-Ring Radiocarbon Data from the Lake Ontario Region, North America, and its Paleoenvironmental Context

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Tree rings are key to calibrating radiocarbon dates with limited error due to their annual record of atmospheric radiocarbon content. Here we report the potential of providing an independent ^{14}C record for the Younger Dryas (YD) into Early Holocene (EH) from a unique source, northeastern North America. It will add a new source for ^{14}C data in the radiocarbon calibration curve, and new perspectives for issues such as variations in the atmospheric record of the northern and southern hemispheres, the timing of the YD/EH transition, and in the CO_2 exchange between atmosphere and ocean, across 1200 years, ca 12,400-11,200 cal BP. The source is the Bell Creek site in the lowlands of Lake Ontario, and its location, sediments, and the abundant log and other organics in the YD deposition give a unique opportunity to understand the development and processes of the paleoenvironment for the region. At the time of deposition, a boreal forest in a riparian environment was evolving, with Early Lake Ontario an evaporative basin, the Laurentide Ice Sheet margin less than 400km to the north, and ongoing isostatic adjustment.

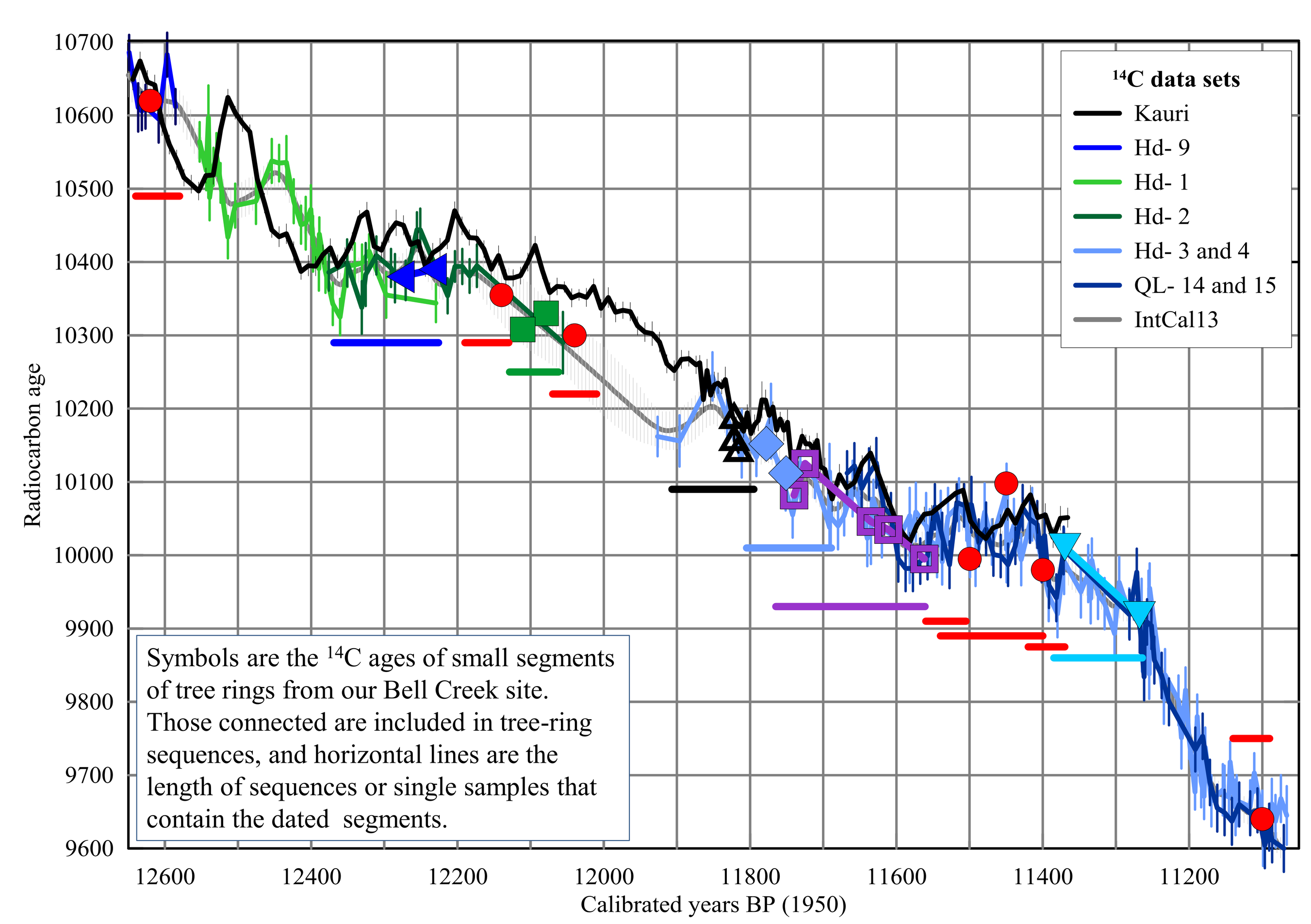

Figure 1. The Bell Creek ^{14}C ages and sets of tree-ring ^{14}C calibration data plotted against the IntCal13 calibration curve (Reimer et al. 2013). A visual comparison of the data sets illustrates the many issues with the current YD ^{14}C record. Note the ~50 year vertical gap in the ^{14}C ages between the kauri and Hd data, due to differences in atmospheric ^{14}C content between hemispheres. Resolving the horizontal offsets of the ^{14}C series is critical in establishing calendar dates from ^{14}C ages in the YD.

Radiocarbon-dating is the primary method for placing events, periods, and processes in time and in chronological order. For the Younger Dryas, ca 13,000-11,700, high-precision tree-ring atmospheric ^{14}C data is limited, both spatially and temporally (Figures 1 and 2). As a result, assigning absolute dates to ^{14}C ages plus understanding the causes of variations in atmospheric ^{14}C content over that period remains difficult.

Spatially, YD tree-ring radiocarbon data sets are currently available from only central Europe for the northern hemisphere (Kaiser et al. 2012) and from Tasmania and a new data set from New Zealand for the southern hemisphere (Hua et al. 2009, Hogg et al. 2015/6) (Figure 2).

Temporally, the atmospheric ^{14}C data available for the calibration curve in the YD is composed of only a few data sets over time (Figure 1). The most problematic issue is the horizontal offsets between data sets which must be resolved for more accurate 14C calibration and chronological order than possible at present.

In addition, to obtain a tree-ring ^{14}C record, quantities of logs with sufficient ring counts are needed to build robust chronologies, and wood preserved from the YD is very scarce.

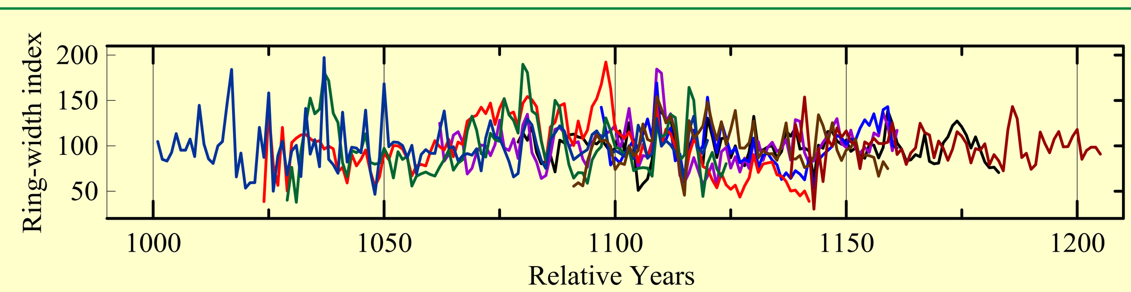

Figure 3. A tree-ring sequence built from 8 samples from both the 2009 collection and the 2015 survey. The "wiggle-match" of their ^{14}C dates are shown in the purple squares in Figure 1.

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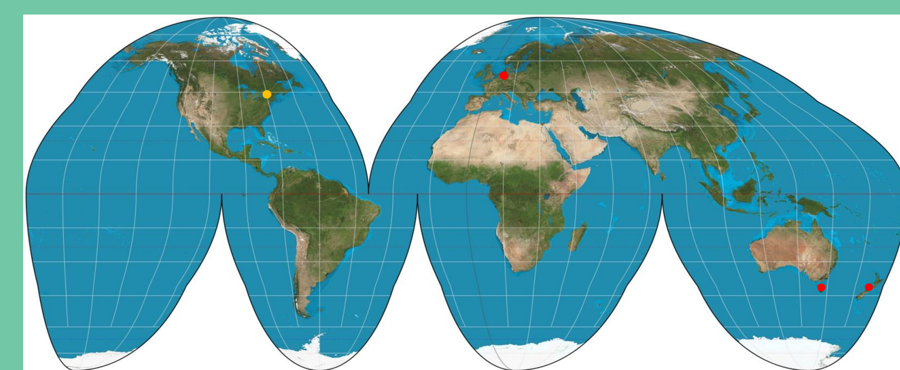

Figure 2. Red circles are the only sources of the YD-EH tree-ring ^{14}C data at present. The orange circle is the Bell Creek site.

Atmospheric ^{14}C content varies from year to year due to variability in the cosmic ray flux which is modulated by both solar radiation and the Earth's magnetic field (Figure 4). It is relatively uniform in the upper atmosphere around the globe due to the rapid distribution of CO_2.

However, **the significant differences** in the ratio of terrestrial to oceanic surface area between the northern and southern hemispheres (~3:2 N and 5:1 S) have been shown to significantly affect the atmospheric ^{14}C content in the lower atmosphere by differences in the atmospheric-oceanic CO_2 exchange. This adds to the difficulty of solving the YD ^{14}C puzzle.

In addition, **non-analog processes** such as the melting ice sheet, varying ocean levels and fresh meltwater affecting ocean circulation, most likely did affect the atmospheric ^{14}C content in many ways during the YD, especially around the North Atlantic Ocean, and those issues contribute to our poor understanding.

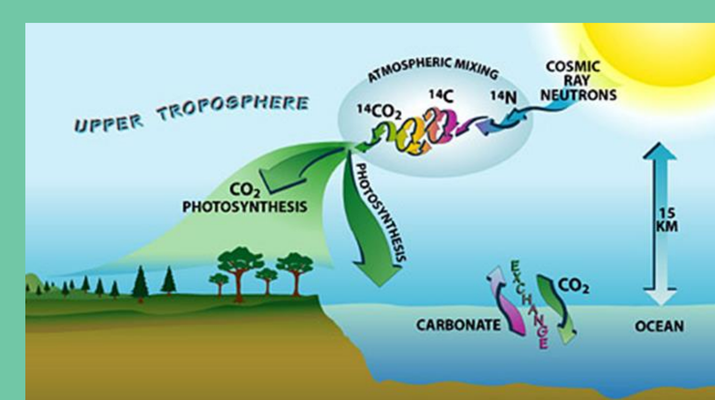

Figure 4. Illustration of the cosmic production of ^{14}C in the upper atmosphere, its subsequent integration into CO_2 and absorption by photosynthesis. Tree rings contain a direct annual record of ^{14}C content due to their annual ring growth, which makes them the best source of high-resolution ^{14}C calibration data.

Our independent ^{14}C data will add another spatial dimension (Figure 2) to the radiocarbon calibration data for the Younger Dryas, and augment the ^{14}C data from ca. 12,400 to 11,200 cal BP (Figure 1), perhaps for the complete 1200 years, and possibly another century or two earlier. Comparisons and analyses of this data with those from the other two sources will unquestionably aid in determining whether there was or was not more spatial variation in atmospheric ^{14}C content, and whether that was continual or varied over time. This will also help in our ability to place YD ^{14}C ages more accurately in time, and in our understanding of the Younger Dryas chronozone.

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The Bell Creek Valley lies in a drumlin field in the lowlands south of Lake Ontario in North America (Figures 5 and 7).

The stratigraphy (top left photo above) indicates first a lakebed, then varying shoreline, river, and streamflow channel deposits over the YD and into the Early Holocene. The lowlands between drumlins were natural channels for streamflow. With the infill of the stream channel, the deposition ended, and the floodplain became a wetland environment.

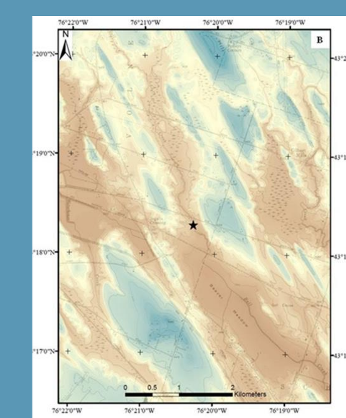
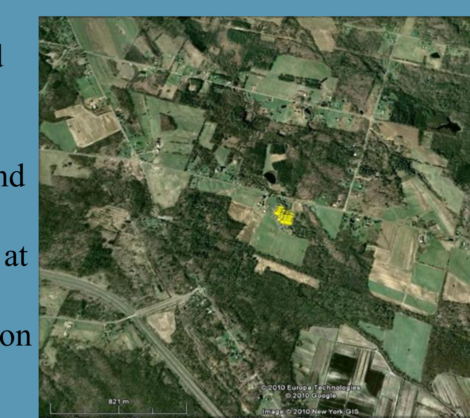


Figure 5. Map and aerial photo of the site, drumlins and topography. Star and pushpins are the location of the site at this scale; the red circles in Figure 7 on the regional scale.



An intense survey last summer (Figure 6) and previous exploratory collection indicated that there are enough logs at the site to build robust tree-ring chronologies and provide significant ^{14}C data sets for the YD-EH.

Over 100 logs were sampled, and a few have been analyzed at present. Many tree-ring sequences have been assembled from the analyzed samples (Figure 3), and many decadal segments have been ^{14}C-dated to assess the period(s) represented by the logs (Figure 1).

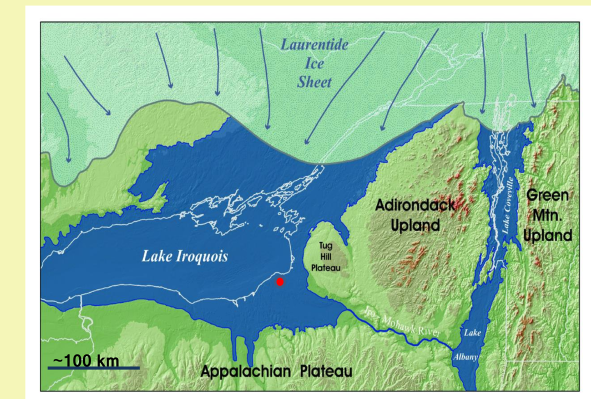
The thickness of **the YD-EH deposit** and abundance of macrofossils and their character indicate a boreal environment. Our field collection includes white spruce cones and needles, possibly black spruce and/or tamarack cones, tamarack and spruce wood.

Figure 6. Aerial photo of the site from a drone camera, showing the locations of the creek, floodplain, and some of the trenches dug during the survey, August 2015 (Bill Hecht)

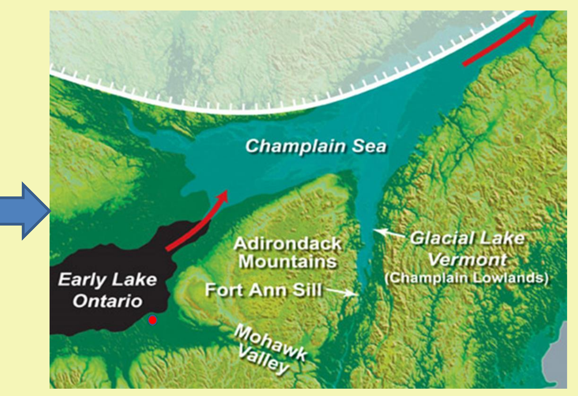
This project will provide a clear record of the changing landscape and climatic processes that affected the environment and its emergence from lakebed into river, then a floodplain with a meandering stream. The extensive sediments and organics in the YD-EH deposit will give a more accurate understanding of the conditions at the site and provide that information for connections and extension across the Lake Ontario region and beyond.

Ralph Bowering and family are applauded for their interest in the buried logs, the initial phone call, and their permission and support in sampling the site. The volunteer field work of many people, including members of the Bowering family, several people from the surrounding community, and fellow colleagues in the initial exploratory collection is greatly appreciated.

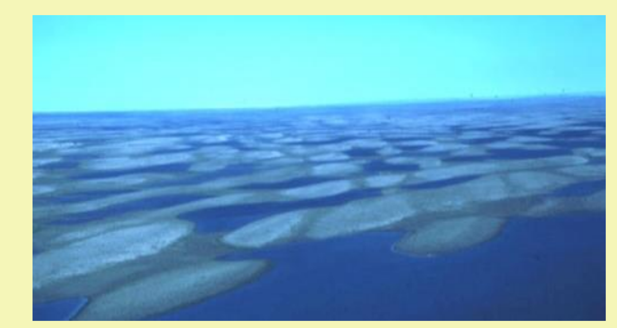
Figure 7. Landscape evolution of the Bell Creek site, pre-Younger Dryas to Early Holocene.



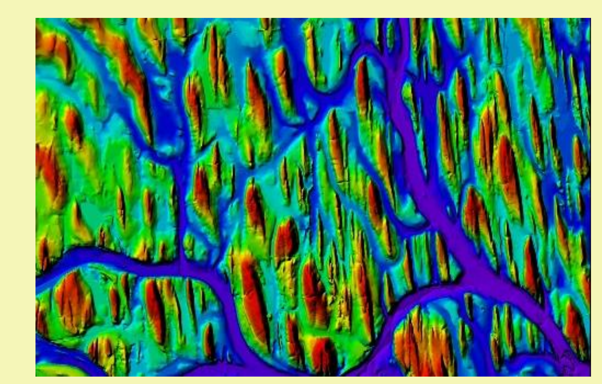
Glacial Lake Iroquois, ~13.5 ka cal BP, which drained ESE into the Mohawk River Valley. The red dot is the location of the Bell Creek site on what became the Lake Ontario lowlands.



Early Lake Ontario (ELO) at ~12.5-9.5 ka cal BP, after the site was exposed. ELO was an evaporative basin, and most of the logs from the immediate riparian floodplain accumulated at the site.



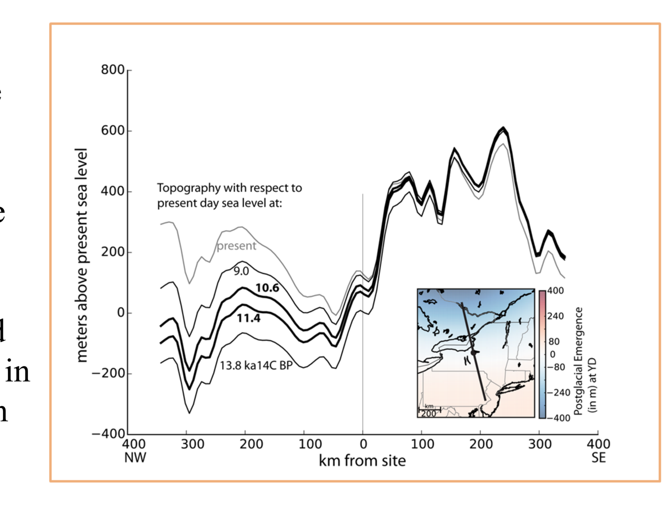
1. Before and during drainage of Lake Iroquois and subsequent proglacial lakes, ~13.5-13.0 ka cal BP. Left: Drumlins on the lowlands were beveled to the Lake Iroquois lake level. Right: The sides and bases of drumlins were further eroded as the lake level dropped.



2. The lowlands between drumlins became river valleys, with possible log deposition from both the floodplain and the surrounding drumlins, ~13.0-12.5 ka cal BP.

3. Meandering river in a boreal setting, most likely the situation at the site in YD-EH, ~12.5 – 11.0 ka cal BP, when most of the logs accumulated.

Figure 8. The emergence of topography at the Bell Creek site on a NNW-SSE transect (see inset). The site sits just south of the Lake Ontario basin where the uplift increased strongly to the north, and north of the Appalachian plateau with limited adjustment. Evidence of change in streamflow direction are found in the sediments at the site.



Acknowledgments: Photographs across the top panel, left to right, were taken by Todd Grote, William Mastandrea, and Carol Griggs. Photos and illustrations in Figures 4 and 7 are from various websites, citations are available on demand.