INACCURACIES IN DEGLACIAL CHRONOMETERS RECORDING LAURENTIDE ICE SHEET (LIS) RETREAT IN THE NORTHEASTERN UNITED STATES: PRESENCE, MAGNITUDE, AND CONTROLS

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When did the LIS begin shrinking?

- Hundreds of core-bottom organic ^{14}C and *in situ* cosmogenic ^{10}Be ages in northeastern U.S. to constrain when LIS margin began retreating from Last Glacial Maximum extent (Fig 1 inset)
- PROBLEM! Ages between methodologies (Fig 2) differ by thousands of years near LGM terminal moraine (Fig 1; Ref 1,2). Especially true for macrofossil ^{14}C ages and ^{10}Be exposure ages
- PROBLEM? Ages agree well when ice margin was >150 km from LGM terminal moraine (Fig 1)
- What is the deglacial chronology of this LIS margin, why do deglacial chronometers disagree in some places but not others, and what are the implications for deglacial chronologies elsewhere?

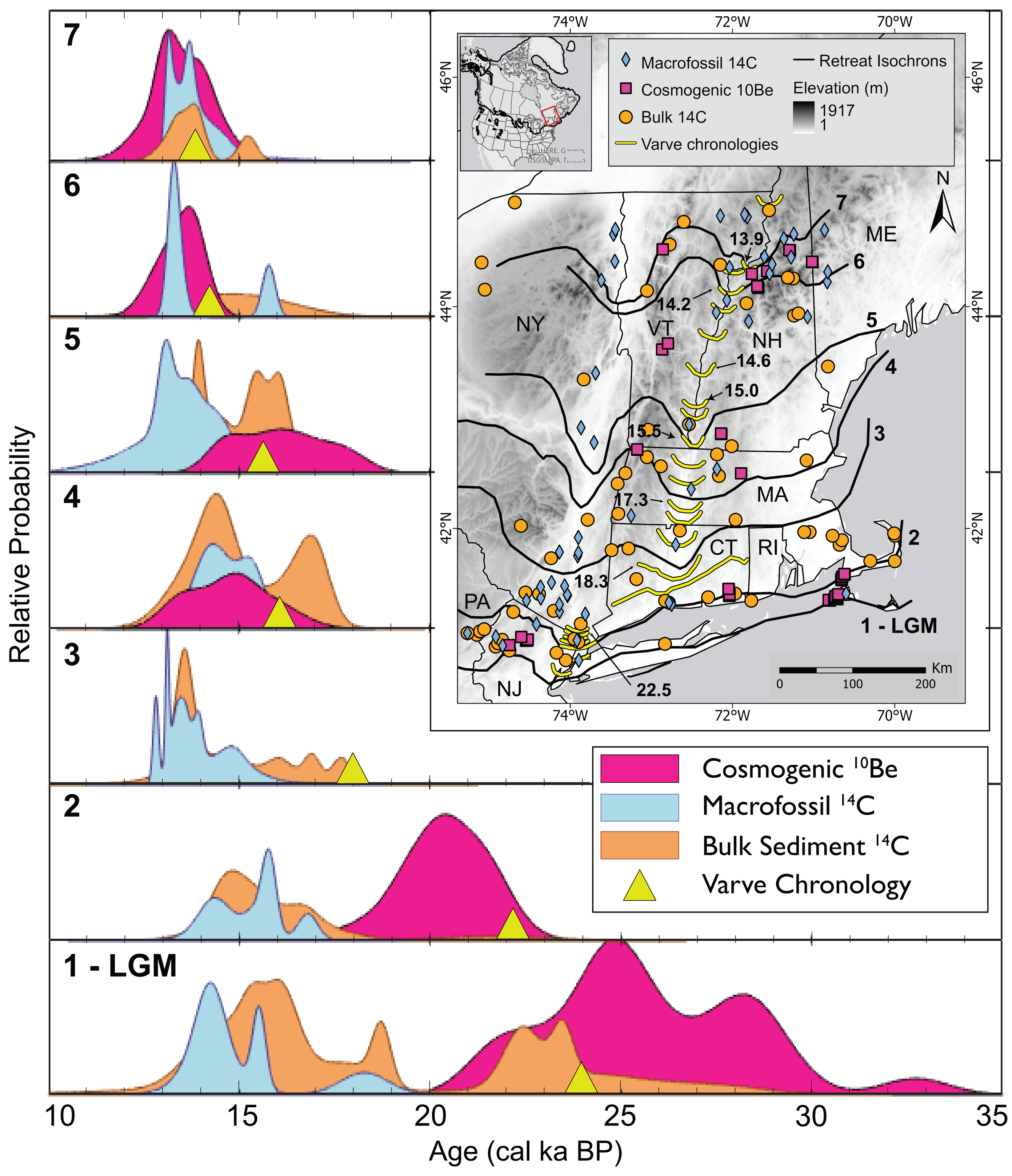

Figure 1: (Inset) Deglacial chronology constraints in the northeastern U.S. Numbers and arrows indicate when the LIS margin was at different locations according to varve chronologies[3,4]. Numbered black lines are ice margin positions corresponding to the panels in the main Fig. 1 plot. (Main) Ages from deglacial chronometers along different ice margin positions as indicated in the inset map. Probability density functions (PDFs) for each chronometer are made by summing the PDFs of individual chronometer ages for each method into one summed PDF.

Varve Chronologies: a 3rd line of evidence

Two in northeastern U.S. (see yellow lines in Fig. 1 inset for locations)

- Terminal moraine to southern NY (24 - 22.5 ka)[3]
  * Calibrated using ^{14}C dating on concretions and bulk sediment in varves
- Southern CT to northern NH and VT (18.8 - 13.4 ka)[4]
  * Calibrated using ^{14}C dating on arctic plant macrofossils in varves
  * All calibration samples within area and age of $^{14}C/^{10}Be$ agreement
- Chronologies are not connected, gap of ~3.5-4 kyr

Problem of Circularity??

- Varve chronologies are calibrated using ^{14}C ages in varves, can we use varves to compare deglacial chronologies based on other ^{14}C ages?
- Perhaps, but two arguments in favor of using varve chronologies as "controls"
  * Older varve chronology calibrated with bulk sediment and concretions. The big age disagreements are between macrofossil ^{14}C and exposure ages.
  * Younger varve chronology is calibrated with macrofossil ^{14}C ages, but at locations where macrofossil ages are in good agreement with exposure ages, suggesting that they are reliable

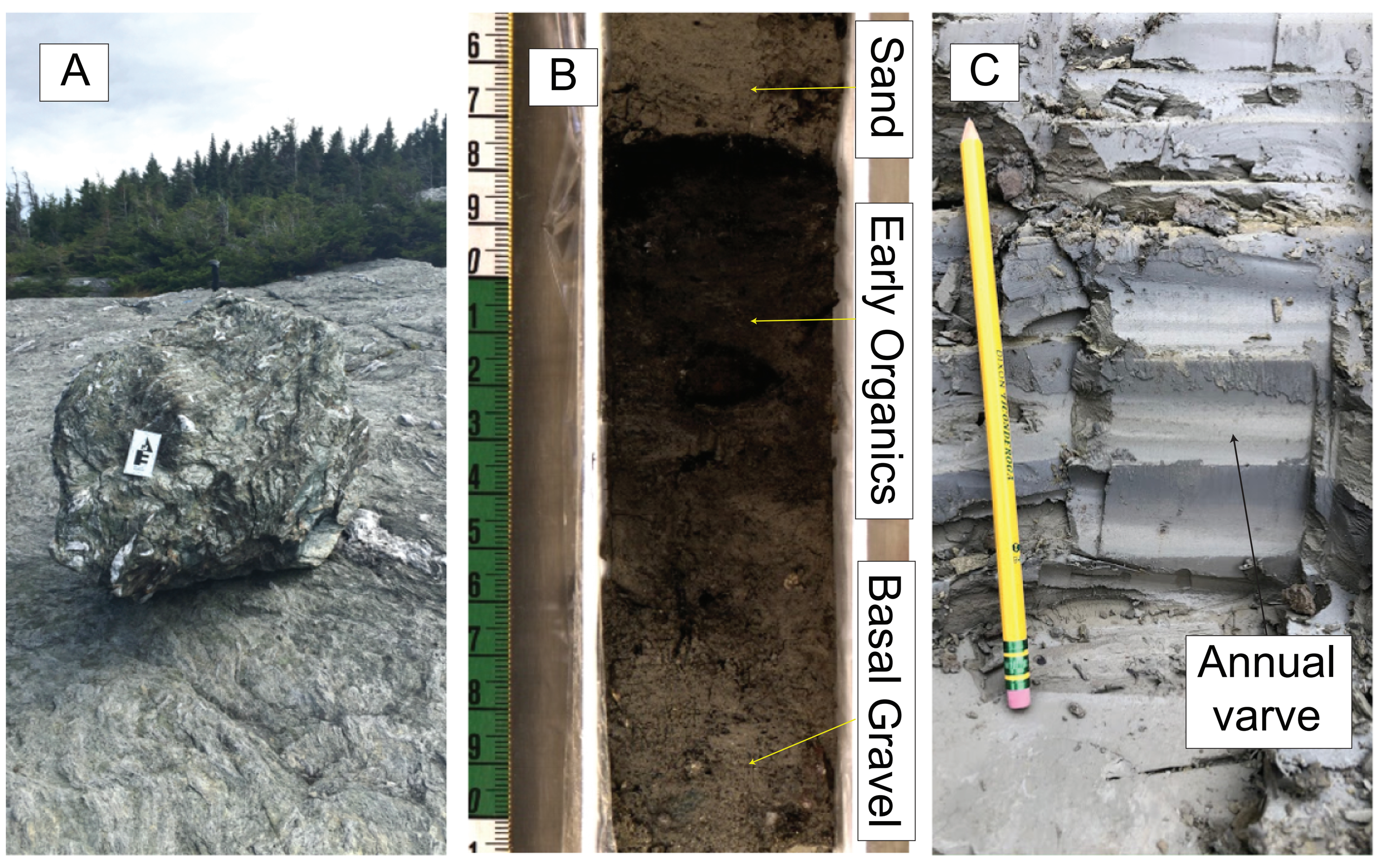

Figure 2: Geochronometers used to constrain LIS margin retreat in the northeastern U.S. (A) glacially-deposited boulder for in situ ^{10}Be exposure dating. (B) Early organic material found near the bottom of a lake sediment core that can be used for either bulk-sediment or macrofossil ^{14}C dating. (C) Rhythmitic glacio-lacustrine sediments interpreted as annual layers (varves).

References

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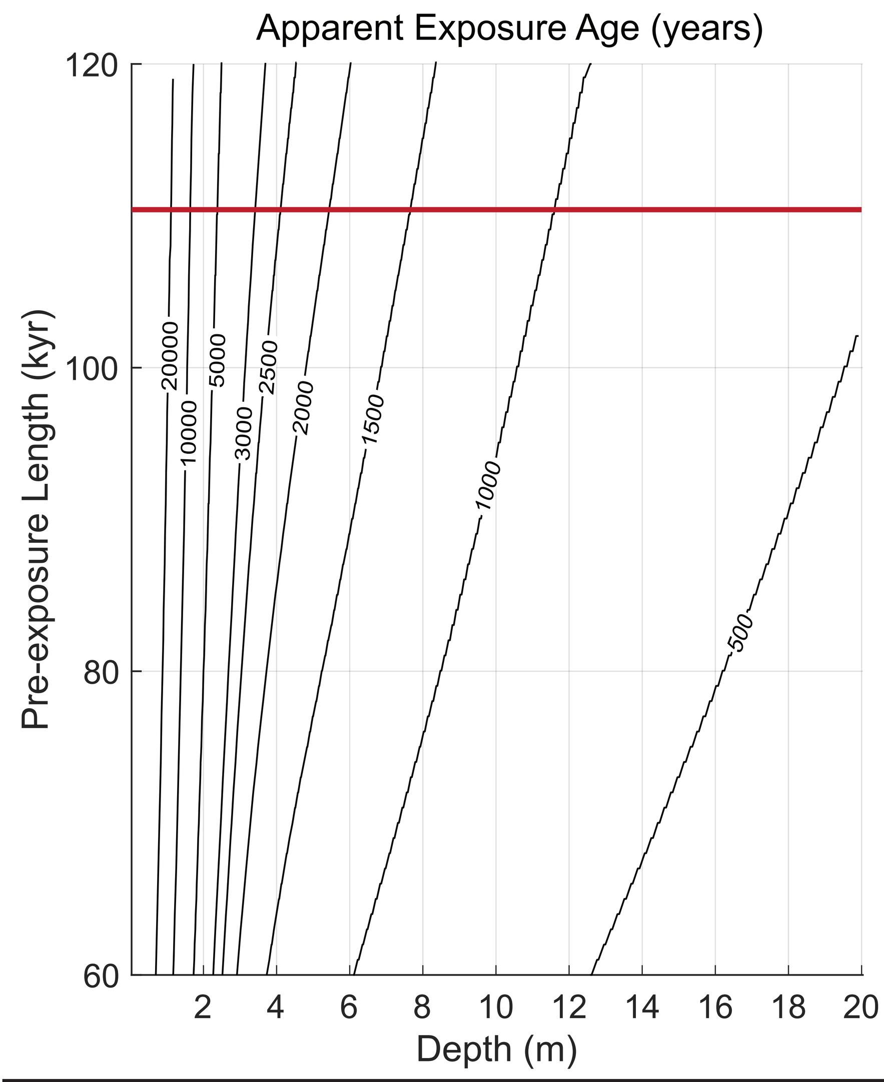
Acknowledgements

This work was supported by NSF EAR-1602280, 1603175, and 1735676

Is ^{10}Be inheritance to blame?



- We modeled the pre-LGM accumultaion of ^{10}Be in bedrock in the northeastern U.S. for different exposure durations (Fig 3).
- Most-likely pre-LGM exposure duration near terminal moraines: 110 kyr (red line).
- >6 m of erosion needed to reduce ^{10}Be inheritance below 2 kyr, >11 m needed to get below 1 kyr

Figure 3: ^{10}Be concentrations (in apparent exposure years) in bedrock at the LGM for different pre-LGM exposure durations

***At least* 1-2 kyr of ^{10}Be inheritance expected in bedrock and boulders near the terminal moraines unless erosion was deeper than expected**

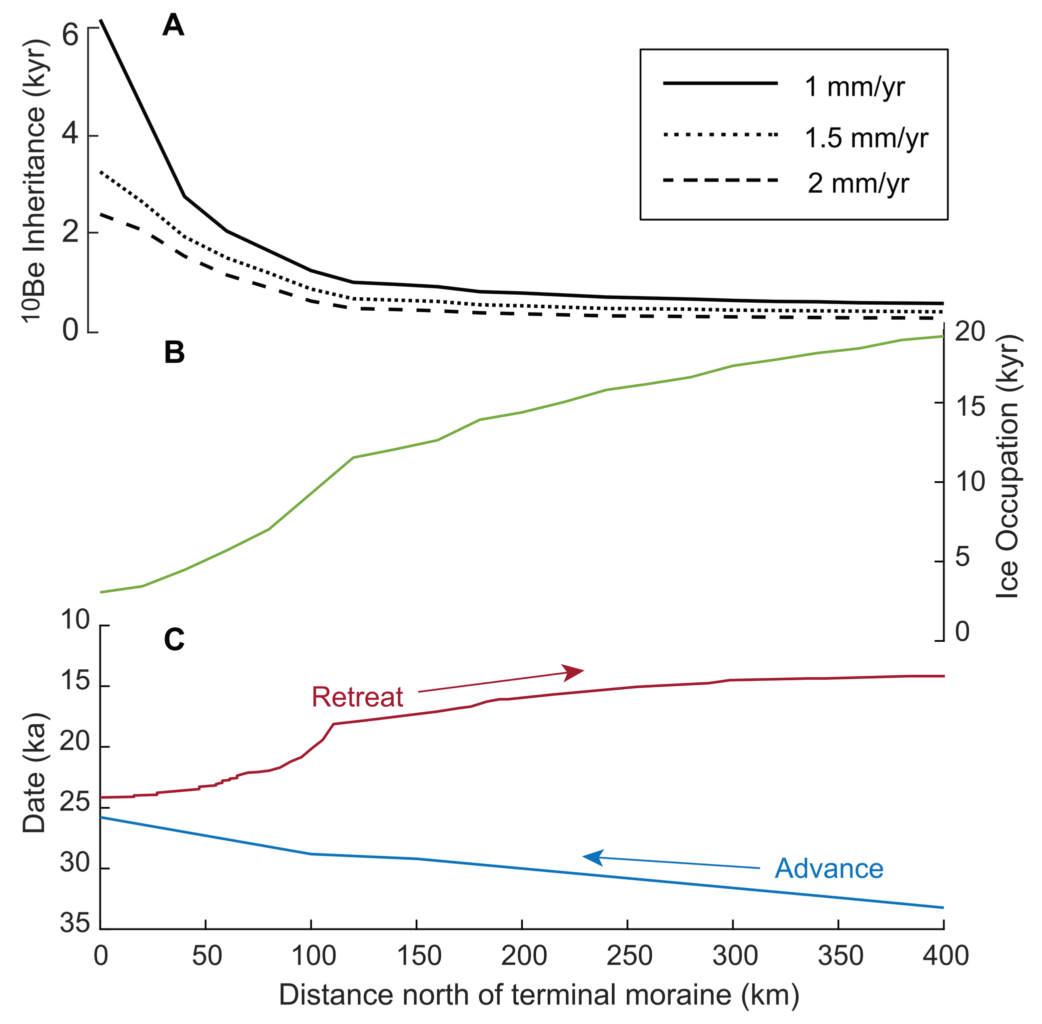


Figure 4: (A) ^{10}Be inheritance modeled for samples at locations near and far from the LGM terminal moraines under different glacial erosion rates. Inheritance is calculated by assuming 110 kyr of pre-LGM exposure (Fig. 3) and ice occupation duration (B) as informed by LIS advance[3,5] and retreat[3,4] chronologies (C).

^{10}Be inheritance decreases rapidly with distance away from terminal moraines, minimal >100 km away

Is delayed vegetation colonization to blame?

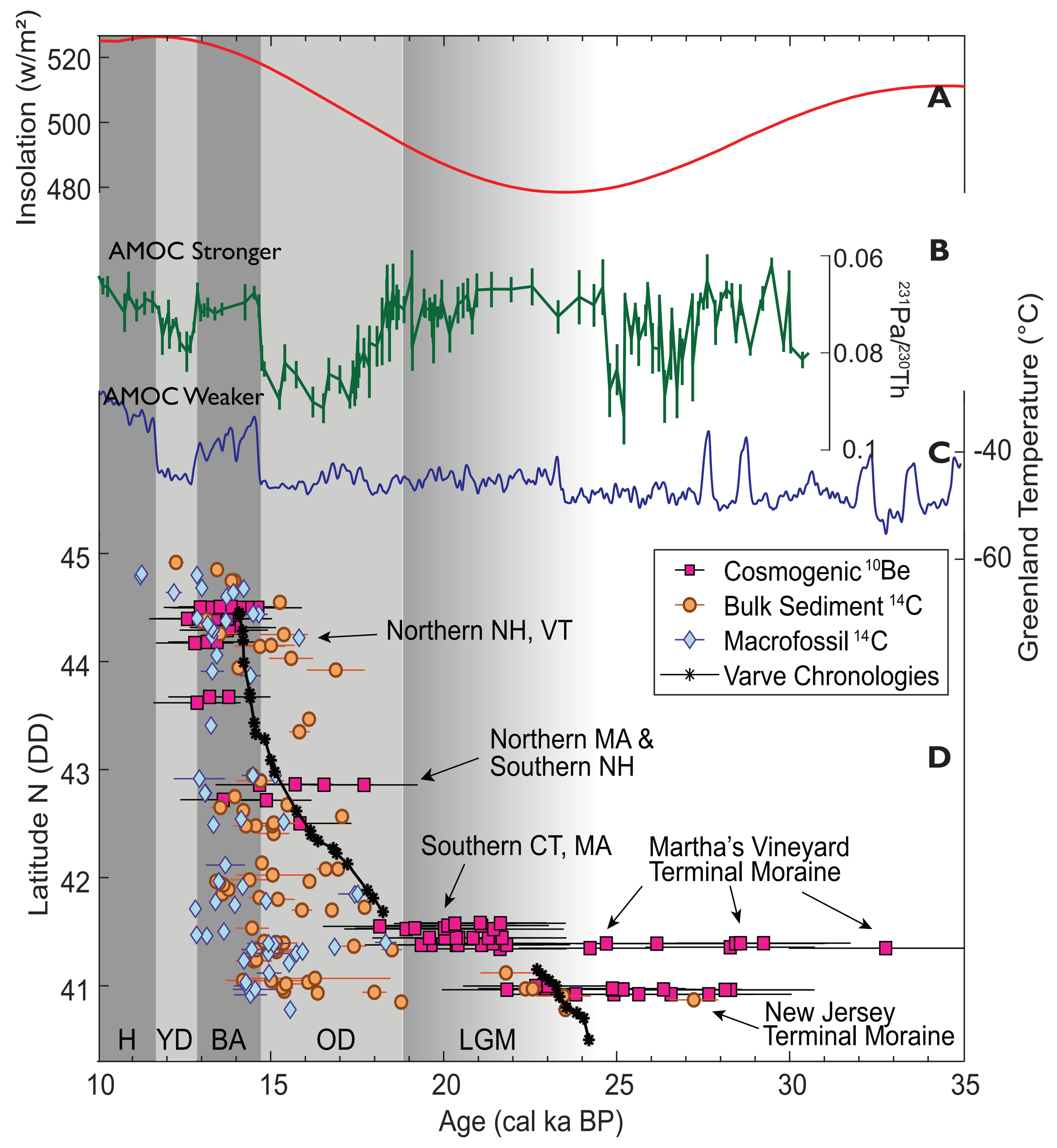


Figure 5: Paleoclimate of the deglacial period in the North Atlantic. (A) Insolation curve for 40°N[6]. (B) Strength of the Atlantic Meridional Overturning Circulation (AMOC) informed by the $^{231}Pa/^{230}Th$ proxy[7]. (C) Greenland temperature reconstruction from the NGRIP ice core[8]. (D) Ice retreat chronometer data from this compilation. OD = Oldest Dryas, BA = Bølling-Allerød, YD = Younger Dryas, H = Holocene.

Cold North Atlantic conditions from LGM to ~15 ka, caused partly by weak AMOC, likely prevented extensive vegetation growth in northeastern U.S., delaying macrofossil deposition in basins

Conclusions

- ^{10}Be exposure ages on or near LGM terminal moraines skewed old by inherited nuclides, likely at least 1-2 kyr, more in boulders quarried from shallower depths
- ^{10}Be inheritence declines rapidly with distance from terminal moraines due to longer ice cover and thus depth of glacial erosion
- ^{14}C ages from macrofossil samples lag deglaciation by 6-8 kyr near the LGM terminal moraines
- Lag between deglaciation and macrofossil sample deposition decreases with distance from terminal moraines due to more conducive conditions for plant growth later in the deglacial period (warmer summer temperatures during late Oldest Dryas and Bølling-Allerød)

Implications

- **^{10}Be inheritance likely in peripheral regions of LGM ice sheets, where surfaces experienced long pre-LGM exposures and relatively brief LGM ice cover and thus shallow erosion.**
- **^{14}C ages from lake cores, especially macrofossil plant samples, may post-date ice retreat during stadial climate periods where ice margins may continue retreating, but harsh periglacial conditions prevent significant vegetation.**