The North American Varve Chronology and Glacial Varve Project

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Ernst Antevs' Masterpiece

Beginning in the 1920's, with an expedition led by Gerard De Geer, Ernst Antevs (1922, 1925, 1928, 1931) assembled several long varve chronologies from the time of recession of the last ice sheet in the northeastern United States and southern Canada. This included the New England Varve Chronology (NEVC), compiled from mostly measurements of varves from glacial Lake Hitchcock (Figure 1). Although not calibrated the NEVC was instantly a valuable tool for determining relative ages and rates of deglaciation across New England where Antevs documented a systematic recession of ice. Unfortunately, an alternative view of ice receding by regional stagnation (Flint, 1929, 1930, 1932, 1933), raised doubts about the validity of the varve chronology. Later, the first radiocarbon ages in New England (Flint, 1956) seemed to contradict the varve count and references to Antevs' work in New England were omitted from the later two editions of Flint's (1957, 1971) widely used textbooks on glacial geology.

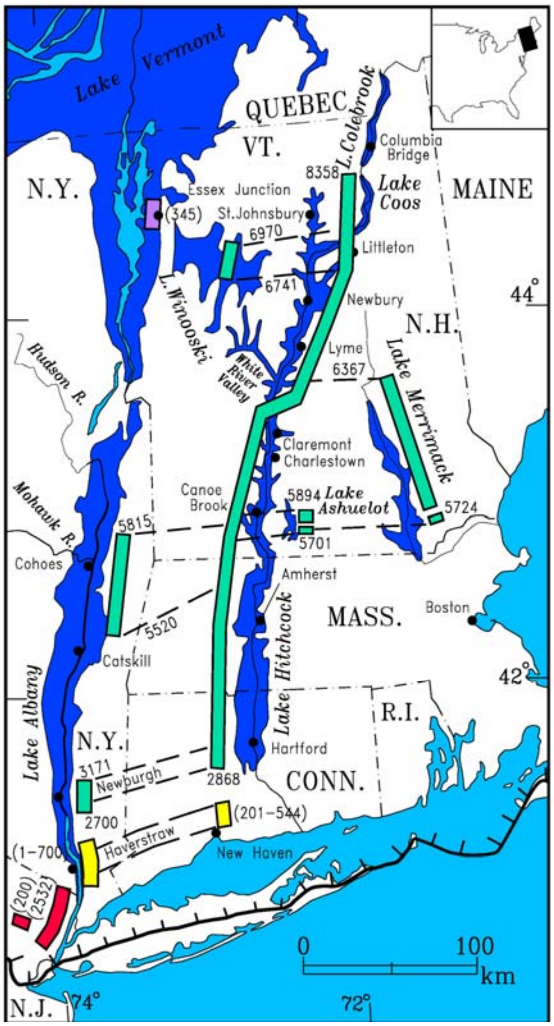
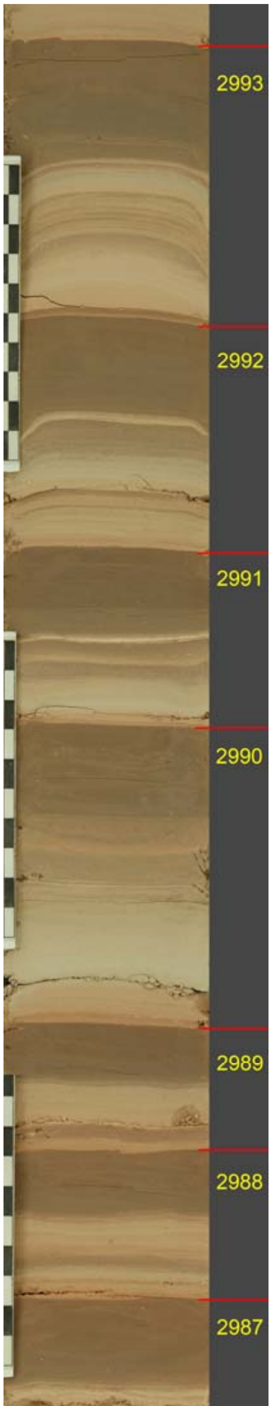


Figure 1. Consolidated and matched varve sequences of the revised NEVC or NAVC (AM 2700-8358 in green) along with other not yet connected long sequences in the northeastern U.S.

Today, early doubts about the validity of the NEVC are unfounded. During and since the 1940's detailed mapping of glacial deposits by the USGS using the morphosequence concept (Jahns and Willard, 1942; Koteff, 1974; Koteff and Pessl, 1981) clearly documents the systematic south to north retreat of the last ice sheet in New England. Also, it is now known that the original interpretations connecting radiocarbon ages to New England's glacial history were incorrect, as documented by many recent radiocarbon ages (Ridge and Larson, 1990; Ridge, 2004; Stone and Ridge, 2009; Ridge, 2012) that when calibrated (Stuiver and others, 2005; Reimer and others, 2009) are in agreement with the length of the varve time scale. In addition, several pioneering paleomagnetic studies on sedimentary deposits took advantage of the varve chronology (McNish and Johnson, 1938; Johnson and others, 1948, Verosub, 1977a, 1977b) in creating paleomagnetic secular variation records. These workers never had difficulty matching new sections to the NEVC and persevered despite a glacial and Quaternary geologic community in the U.S. that was less than enthusiastic.



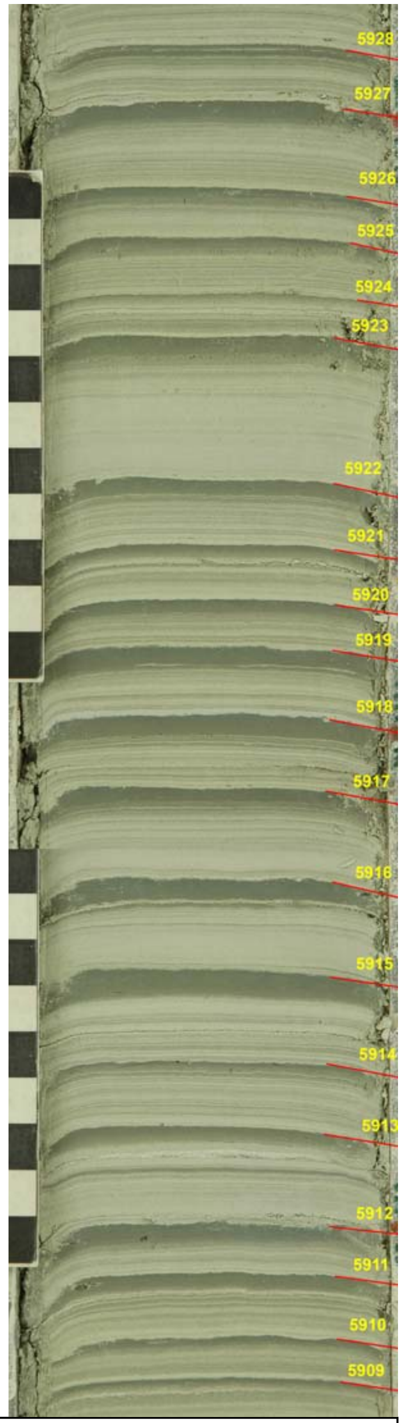


Figure 2 (left). Thick ice-proximal varves (stitched images of AM 2987-2993) from a deep core at Glastonbury, CT where varves from Lake Hitchcock are red as a result of glacial erosion of source rocks in the Mesozoic Hartford Basin. Red lines indicate varve couplet boundaries at the tops of winter (non-melt season) clay layers that have a dark color on partially dried cores. Scales in centimeters. Figure 3 (right). Ice-distal varves (stitched images of AM 5909-5928) from a deep core at North Hatfield, MA. Glaciation of metamorphic rocks in northern New England accounts for the gray color of the sediment. Scales in cm.

The North American Varve Chronology

More than 90 years after Antevs began his work on varves in North America there is renewed interest in varve chronology. With a detailed study of key varve sections we have accomplished the first update of the NEVC, which we call the North American Varve Chronology (NAVC; Figure 1), and are optimistic that the chronology will soon spread to other areas of the northeastern U.S. and Quebec. NSF funding for the recovery of subsurface cores (Figures 2-5) of glacial varve sections (up to 50 m) has allowed us to fill a major gap in the NEVC near Claremont, NH. The chronology has been extended into late glacial time, with the measurement of almost 1300 paraglacial varves at Newbury, VT (Ridge and Toll, 1999) and North Haverill, NH (Figure 6), representing a time when ice was no longer feeding meltwater to the Connecticut Valley. The drilling project has provided us with cores that replicate most of Antevs chronology from central Connecticut to northern Vermont and New Hampshire. With careful core splitting, preparation, and digital imagery this has allowed us to make corrections to parts of the chronology where Antevs may have had difficulty defining the boundaries of thin varves on outcrops of very moist sediment (Figure 4). Given the field conditions under which Antevs measured varves the reproducibility of the old NEVC is astounding and we have had to make very few corrections. Our project has also accumulated many new radiocarbon ages from the varves that now total 54, span 4800 varve years, and have established a more accurate calibration. The new NAVC is a renumbered continuous 5659 year sequence (NAVC numbers 2700-8358) dating from 18,200-12,500 yr BP.

Several projects and findings have been the outgrowth of the new NAVC. The revised varve chronology and new cores have expanded the deglaciation record of New England that is linked to a calibrated time scale and has served as a local calibration tool for cosmogenic dating (Balco and others, 2009). The varves provide a precise chronology that records flood events that were triggered by the release of water from ice-marginal tributary lakes and drops in lake level. The varve stratigraphy chronologically constrains isostatic rebound that decanted water from postglacial lakes in the Connecticut Valley.

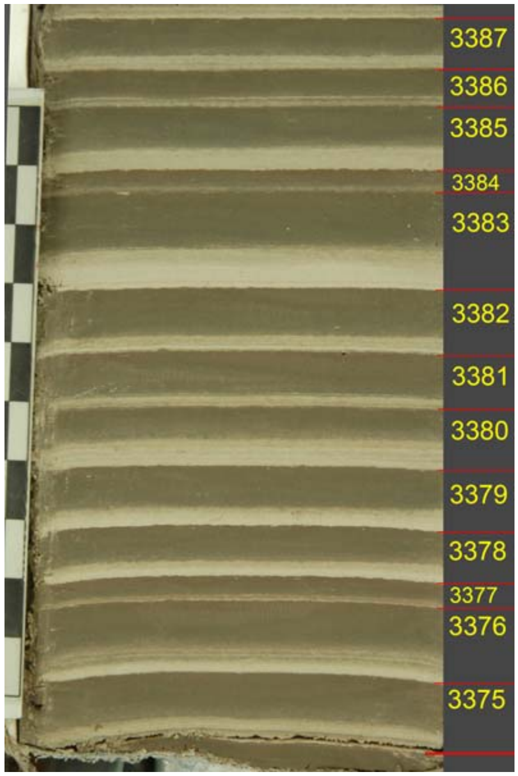


Figure 4 (above). Ice-distal varves (AM 3375-3387) from an outcrop core collected in the clay pits of Redlands Brick Company in South Windsor, CT. Varve 3384 was missed by Antevs' original NEVC and was included as a part of the varve beneath it. This new varve has been included in the revised numbering of the NAVC. Antevs' measurements did include varve 3377, which is also very thin. Scale in cm.

Figure 5 (right). Ice-proximal varves (stitched images of AM 6273-6277) from a deep core in the Perry Hill basin in North Charlestown, NH. The dark bluish-green layers are winter layers. The bottoms of the summer (melt season) layers show muddy diurnal units deposited at the beginning of the melt season when glacial meltwater discharges were relatively low and night time temperatures probably dropped to below or near freezing. Scale in cm.

The new cores will allow a detailed analysis of the intra-annual layering of varves from a wide variety of glaciolacustrine environments. Varves in the Connecticut Valley range in thickness from a few meters in ice-proximal areas (Figure 5) that transition to sub-centimeter varves in ice-distal and paraglacial settings (Figures 4 and 6). The varves also record valley side and tributary embayment vs. deep basin deposition, and have also been collected from prodeltaic and shoaling environments. This analysis is greatly aided by our ability to capture high-resolution digital images of partially dried cores that show the details of intra-varve stratigraphy. We should be able to add tremendously to the pioneering analysis of varve deposition in Lake Hitchcock conducted by Gail Ashley (1972, 1975) nearly four decades ago, a heroic effort at a time when the validity of the varve chronology was not generally accepted.

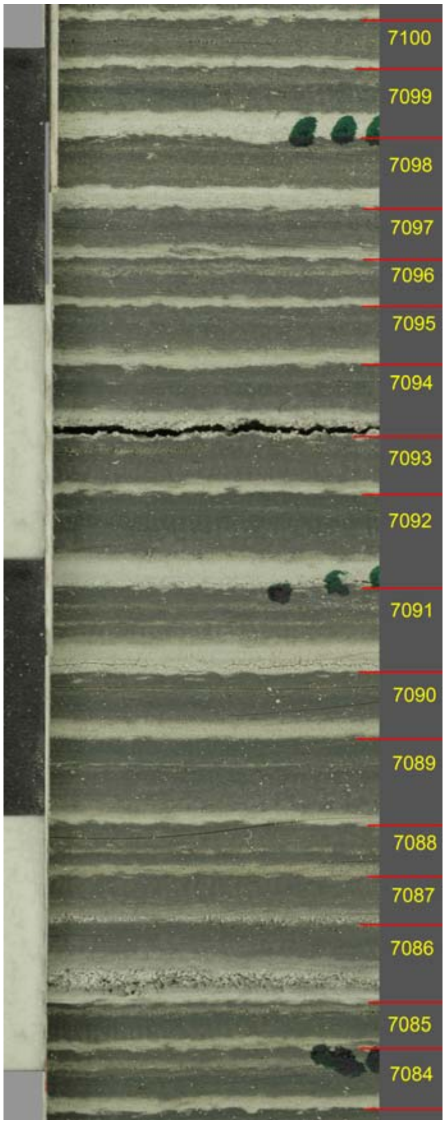


Figure 6 (left). Sub-centimeter paraglacial varves (stitched images of AM 7084-7100) from an outcrop core at North Haverhill, NH. Varves from this time in the Connecticut valley were deposited after the glacier had receded from the basin and varve sediment is derived from runoff and erosion of a newly deglaciated landscape. The winter layers of these varves have tops that were disturbed by bioturbation. The winter layers are also split by a fine sand and silt parting of unknown origin that may be related to fall overturning, which re-energized bottom currents in the lake after the initiation of clay deposition. Scale in centimeters. Figure 7 (above). Piscine trace fossil Undichna unisulca from a varve section at Newbury, VT (from Benner and others, 2009). Scale bar is 2 cm.

The varves have abundant trace fossils that record the pioneering inhabitants of New England's glacial lakes and drainage systems following glaciation. In addition to the ubiquitous small traces left by insect larvae and nematodes there are large traces left by at least two varieties of fish (Figure 7; Benner and others, 2008, 2009) and a notostracan crustacean (Knecht and others, 2009). Although sometimes sparse in the sediment ostracodes occur in all the varves and may provide ecological or isotopic insights about glacial lake environments of the Connecticut Valley.

Changes in varve thickness that are sometimes abrupt, and have been identified as cyclic (Rittenour and others, 2000) are dominantly related to changes in meltwater production, which is a function of glacial melting and therefore climate. Decreases in varve thickness are associated with cool intervals that stimulated small glacial readvances and the building of end moraines, while sudden increases in varve thickness are associated with dramatic increases in the rate of ice recession to up to 300 m/yr in northern New England at about 14,600-14,000 yr BP (Figure 8). This climate record is similar to a Greenland Ice Sheet oxygen isotope record (GISP2) with not only matching stadial events but very similar patterns at a bi-decadal scale (Ridge and others, in review). The varves are presently being studied for their ^{10}Be composition to determine if they record the fallout of this cosmogenic isotope thus providing a global correlation of climatic events with unprecedented accuracy.

The North American Glacial Varve Project

A complete compilation of the NAVC in addition to many other varve sections is on our project web site ("The North American Glacial Varve Project", see; http://geology.tufts.edu/varves; Ridge, 2012) that serves as a data repository in addition to serving as an educational and

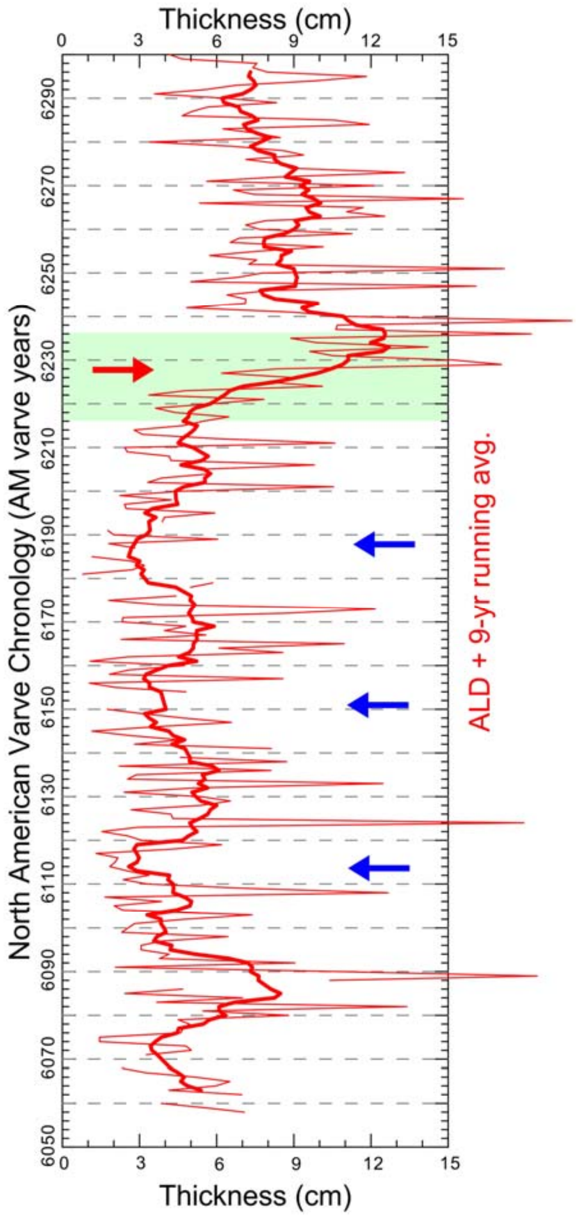


Figure 8. Abrupt climate change event (sudden warming) in a deep varve core from the Aldrich Brook core site in Westmoreland, NH. The sudden warming event terminates a period of small glacial readvances and end moraine construction at North Charlestown, NH and represents the beginning of rapid ice recession at 300 m/yr. ***A.*** *(left) Stitched images of varves (AM 6216-6236) showing abrupt transition to thicker varves at AM 6229 when meltwater supply to the Connecticut Valley suddenly increased. Scales in centimeters.* ***B. (above)*** *Plot of varve section (actual = thin line, 9-yr running average = thick line) showing sudden increase in varve thickness (red arrow). Blue arrows indicate times of low varve thickness that correspond to minor readvances and end moraine construction. Green area is time covered by core image.*

research resource on glacial varves, varve chronology, and methods for studying them. The opening page of the web site features the “Varves of the Month” and a menu linking the user to information and data on the NAVC, information on varve deposition, stratigraphy, field and lab methods, and a glossary of terms associated with varves. All of the varve records associated with the old NEVC in addition to new records from outcrops have been translated to the NAVC numbering system and are available for download in both the NEVC and NAVC numbering system along with all the radiocarbon ages so far obtained from NAVC varves. We also provide information on collecting varve cores and how we produce our high resolution images that allow the detailed study of intra-annual stratigraphy. Users may download the program and its instructions that we use for measuring varve thicknesses on successive varve images from a core. The web site provides many high resolution images and varve plots that may be used for teaching and in the near future we hope to add sections to the web site on varve deposition, varve paleontology, and educational activities.

Acknowledgements

The authors would like to thank the National Science Foundation’s Sedimentary Geology and Paleobiology Program and the Dept. of Earth and Ocean Sciences at Tufts for their support of this project. The drilling services of the USGS enabled the recovery of deep cores. Jacob Benner (Tufts, Earth and Ocean Sciences) has been instrumental in programming the web site. Special thanks go to the former

undergraduate students at Tufts (with current addresses) who worked on this project: Robbie Bayless (Schlumberger D&M), Catherine Beck (Rutgers University), Jody Dean, Laura Carter (Univ. of Bristol, UK), Emily Voytek (Univ. Minnesota Duluth), and Jeremy Wei (Univ. of Massachusetts, Amherst).

Image downloads

For high resolution copies of the images in this article please visit the home page of The North American Glacial Varve Project web site at: http://geology.tufts.edu/varves. Users are free to use the images for educational purposes. Use of the images in other publications or on other web sites is permitted as long as the images are fully cited to this article or to Ridge (2012) in the references below.

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