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Glacial Geology and Surficial Processes in Hanover, NH

School of Ice – Justin Stroup

Introduction

Much of the topography of Hanover, NH, and the Upper Valley region of NH and VT results from landforms created at the end of the last ice age. At this time, the Connecticut River Valley was a remarkably different place. Today, you will have the opportunity to examine some of the evidence for these former environments.

Objectives

We will visit various locations on the Dartmouth campus, near Occom Pond, and in Pine Park and to learn how to interpret past depositional environments from **sediments** and **landforms**.

Much of the evidence for glaciers in Hanover is recorded by sediments that have not yet been lithified (turned to rock) because they are relatively young! You will learn how to observe and interpret sediment properties of these recent deposits. Properties of sedimentary rocks like composition, grain size, sorting, shape and maturity can also be applied to sediments.

Other evidence for past glaciers in Hanover is recorded by **landforms**. The field of **geomorphology** uses landforms to interpret geological processes that shaped the landscape we see today. You will learn to identify different landforms and interpret past depositional environments from these.

Background

During the last ice age, known as the *Wisconsinan Ice Age*, a large ice sheet (the *Laurentide Ice Sheet)* covered much of northern North America (Fig. 1). Along the east coast of North America, the Laurentide Ice Sheet extended as far south as Long Island, NY and Cape Cod, MA. In fact, Long Island and Cape Cod are glacial moraines (linear ridges of sediment deposited at the margin of a glacier).

At ~21,000 years ago, the Laurentide Ice Sheet reached its maximum extent, marking the coldest time of the Wisconsinan Ice Age. Subsequent to this time, climate began to warm causing the Laurentide Ice Sheet to melt and *recede* northward. It is estimated that Hanover was deglaciated ~14,100 years ago (Ridge, 2004). The last remnant of the Laurentide Ice Sheet exists in Baffin Island, Canada. It is known as the Barnes Ice Cap.

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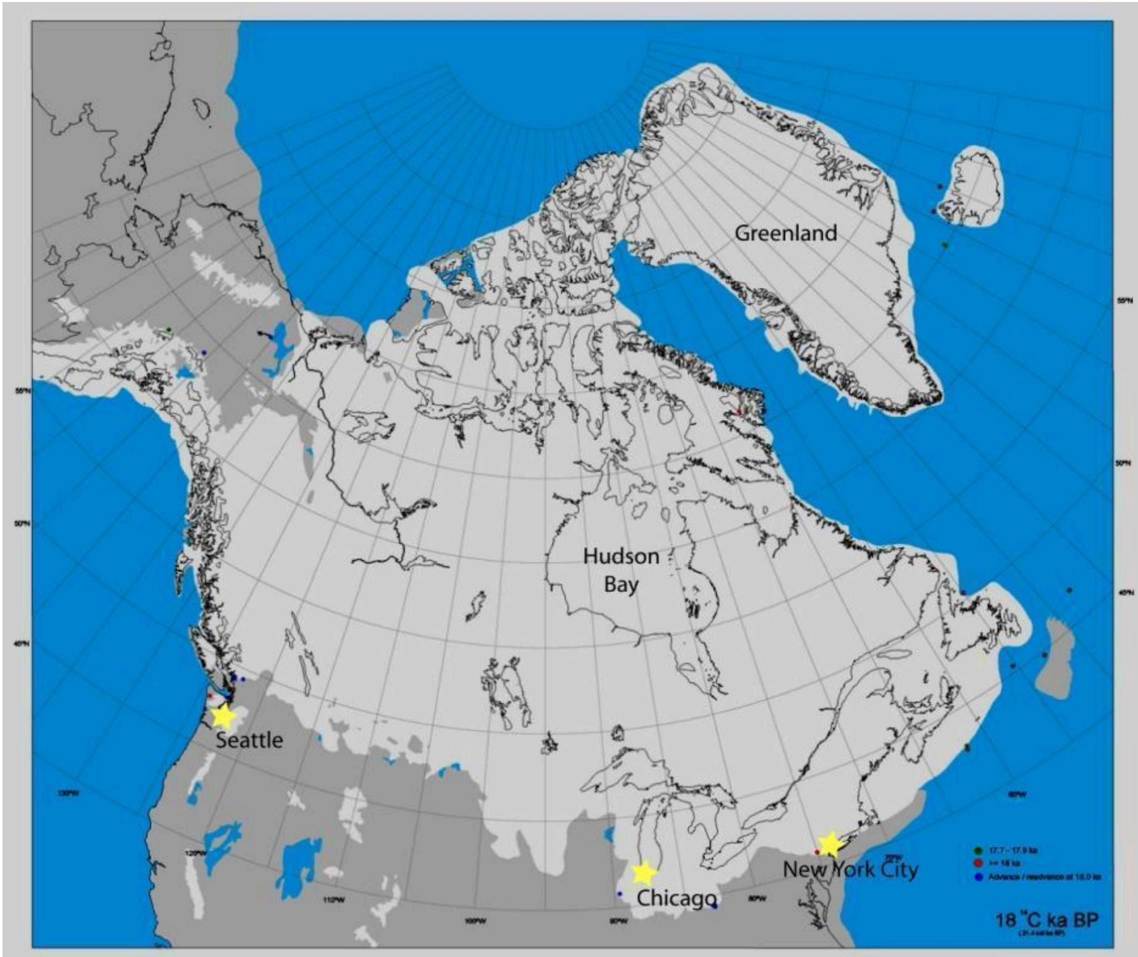

Fig. 1. The extent of the Laurentide Ice Sheet at its maximum, at the end of the last ice age (~21,000 years ago). Image from Dyke et al. (2004).

As the Laurentide Ice Sheet receded northward, large lakes formed south of the ice sheet margin filling the Merrimack, Connecticut and Hudson River valleys (Fig. 2a and b). These lakes were fed by meltwater from the ice sheet and were dammed to the south by glacial sediments. The lake that filled the Connecticut River Valley was known as *Glacial Lake Hitchcock*, after Charles Hitchcock, a Dartmouth Professor and State Geologist of New Hampshire. Glacial Lake Hitchcock persisted for ~4,000 years until its dam was breached and the lake drained.

Meltwater from the ice sheet and nearby streams delivered sand, silt and clay to Glacial Lake Hitchcock. The sediments were deposited on the floor of Glacial Lake Hitchcock and built up to the level of the Dartmouth Green and the golf course. These sediments were deposited only ~15,000-12,000 years ago and, thus, are not yet lithified. Therefore, these sediments are easily eroded by streams.

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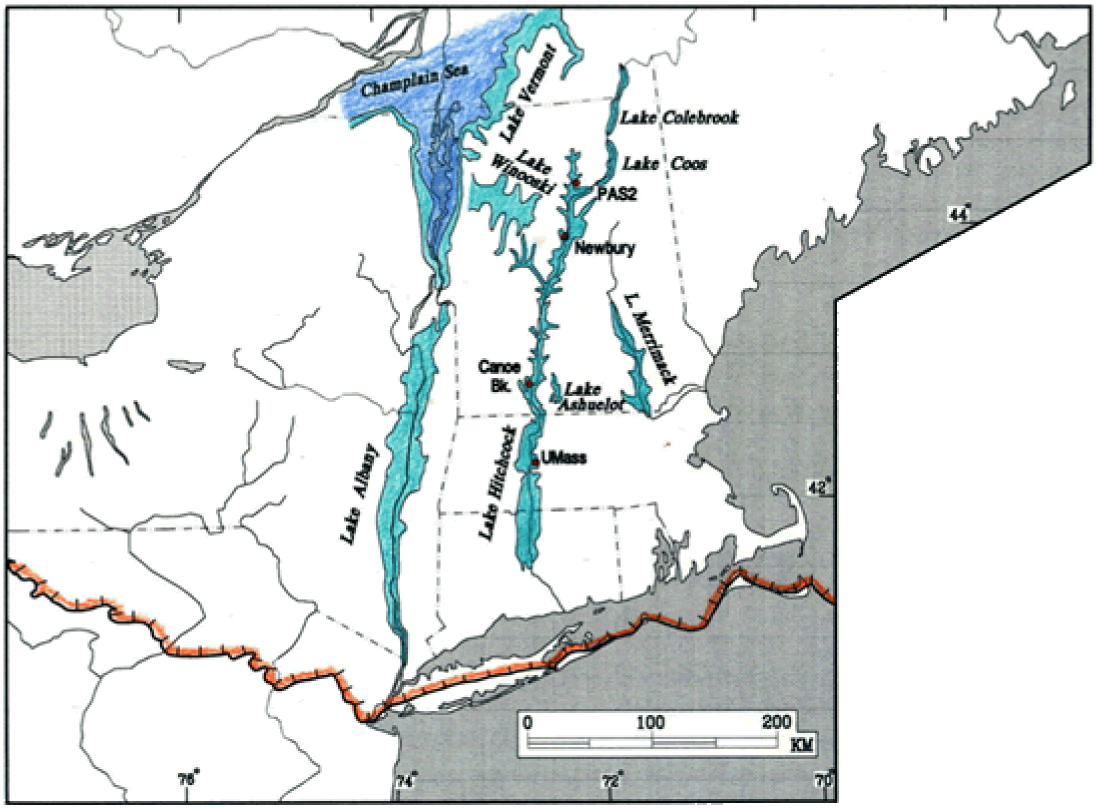

Fig. 2a. The extent of Glacial Lake Hitchcock in the Connecticut River Valley subsequent to recession of the Laurentide Ice Sheet. Image from Ridge (2008).

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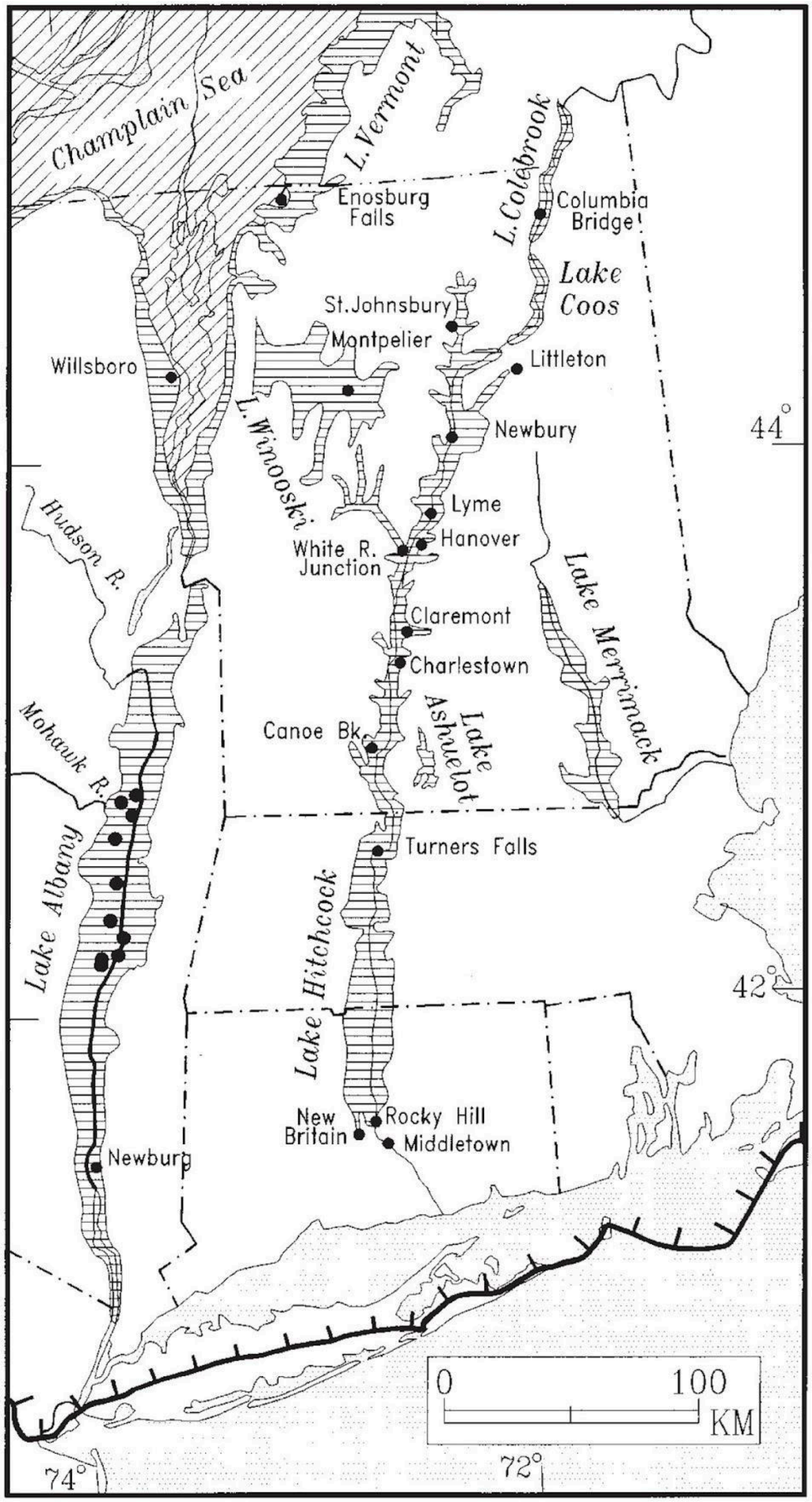

Fig. 2b. The extent of Glacial Lake Hitchcock in the Connecticut River Valley subsequent to recession of the Laurentide Ice Sheet. Image from Ridge (2008).

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<u>**Glacial Sediments in the Hanover Area – Till, Varves, and Esker Sediments**</u>

The landscape of Hanover was eroded down to bedrock by the Laurentide Ice Sheet. As it retreated, the ice sheet deposited a layer of **till** or very poorly sorted sediments. As it retreated, the ice sheet margin was in direct contact with Glacial Lake Hitchcock, a proglacial lake.

Deposition in Glacial Lake Hitchcock covered the till and began to fill the landscape with **glacial varves**. These lake sediments consist of a summer and winter layer which together can be counted as one year (Fig. 3a). The summer layer of a varve consists of sand- and silt-sized sediments that were eroded below the ice sheet and transported to Glacial Lake Hitchcock by meltwater. The thickness of the summer layer reflects the proximity to the ice-sheet margin and how much melting occurred. The winter layer of a varve consists of mostly organic-rich clay. It is only in the winter that these very small grain sizes could be deposited because 1) in the winter Glacial Lake Hitchcock was ice covered and therefore winds did not affect lake circulation, and 2) in the winter there was no meltwater or and little sediment transported from the ice sheet to the lake.

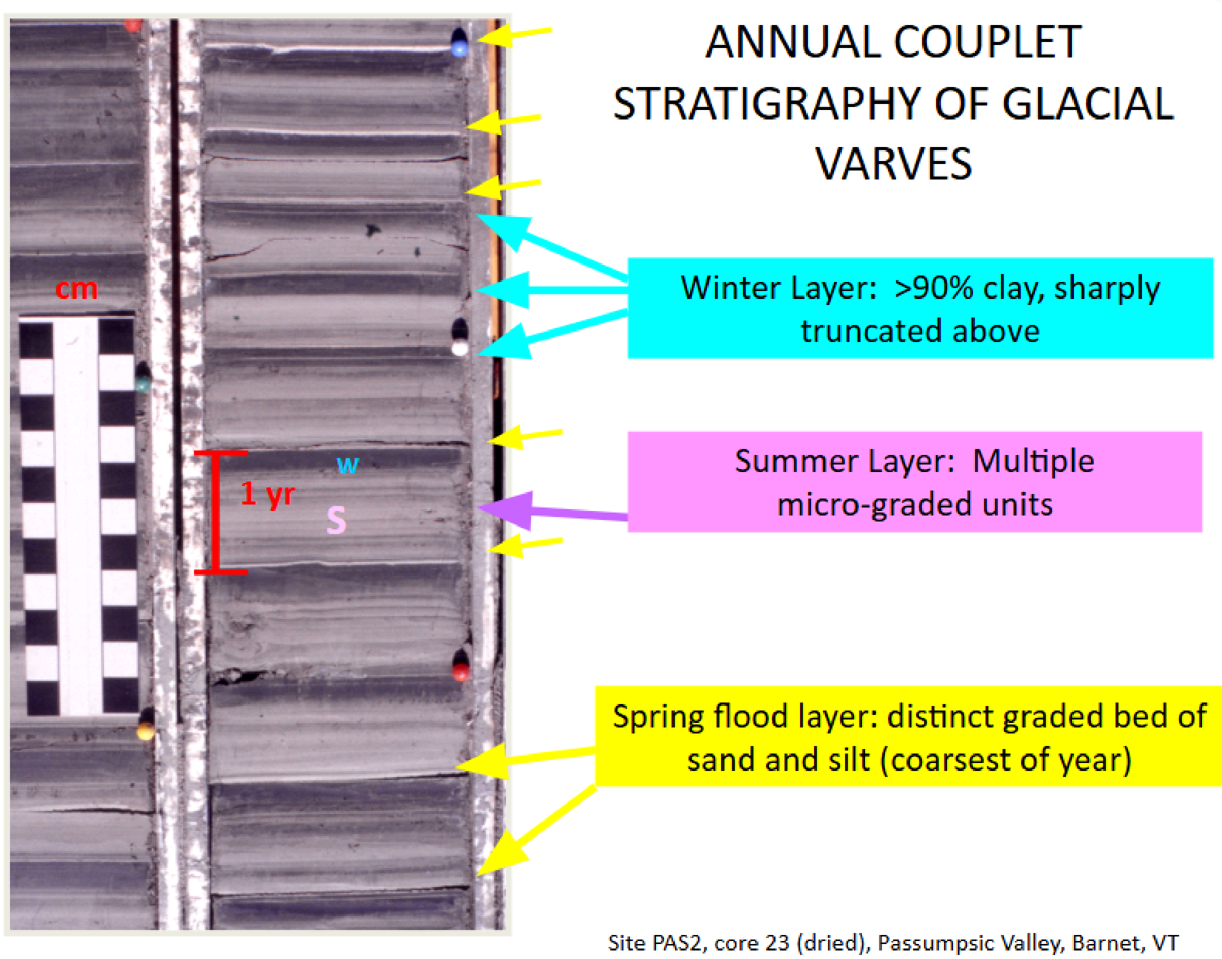

Fig. 3a. Example of varves. Summer and winter layers provide an annual resolution record of lake deposition.

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An **esker** is a ridge of sediment typically oriented parallel to ice flow. It is the filling of a tunnel that once existed and drained water beneath an ice sheet (Fig. 3b and c). Water flowing below the ice sheet has a high discharge (remember "Q" from the lecture and lab on streams). Therefore, esker sediments are typically large grain sizes – from sand to cobbles (fist-sized sediment) and are rounded from transport by fast-flowing water.

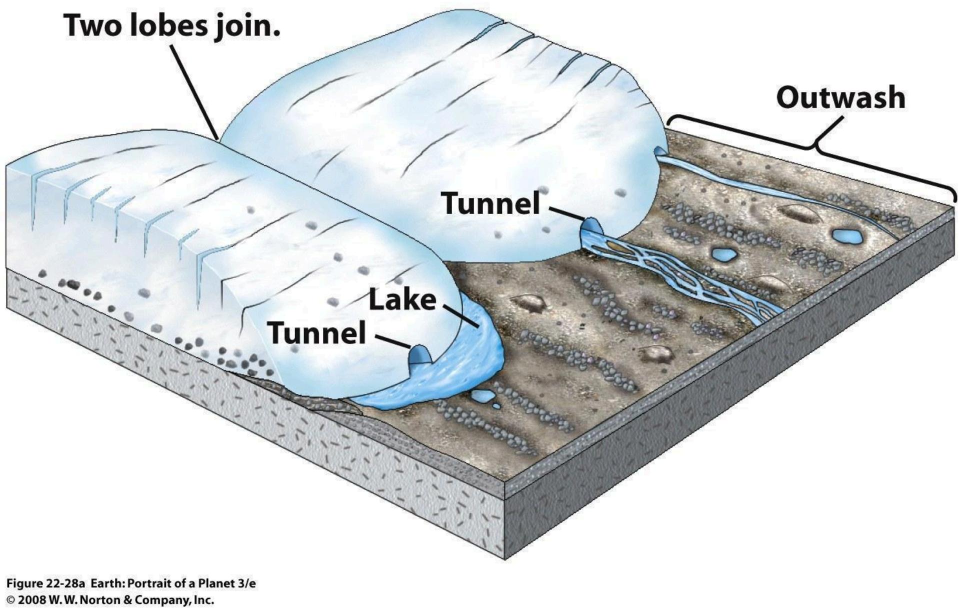

Fig. 3b. Image showing a receding ice sheet and ice marginal processes. Note the proglacial lake forming and the stream emanating from a tunnel at the ice sheet margin.

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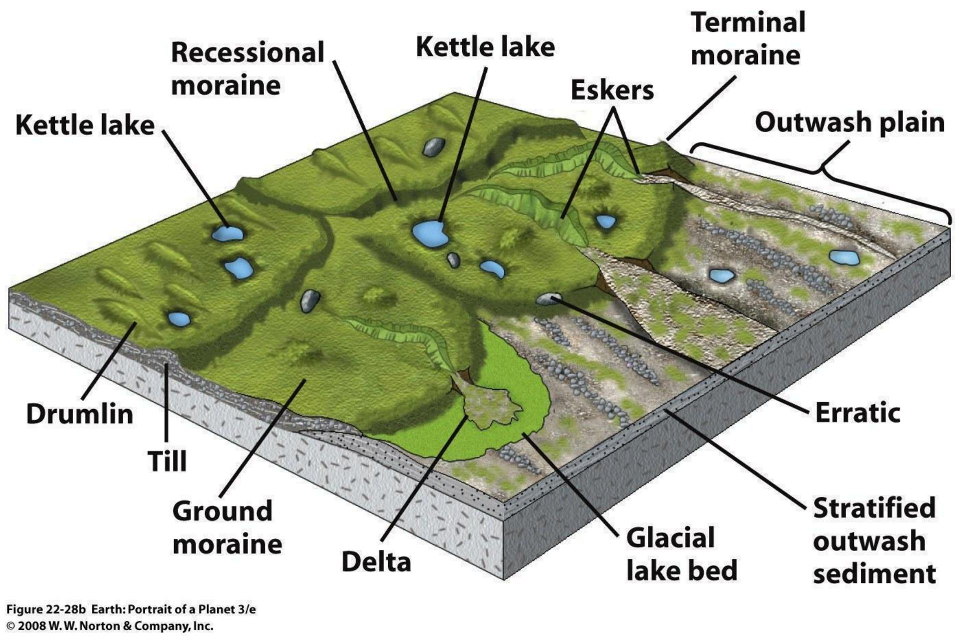

Fig. 3c. Image showing the resulting landscape formed by the ice sheet in the top figure. Geomorphic features to note are a glacial lake bed and eskers. Images from Marshak (2009).

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Field Trip Stops

Many locations on campus offer clues to the past that can be applied to interpreting the geologic history of the region. We will focus mainly on the Occom Pond and Pine Park areas but other locations help to provide needed context.

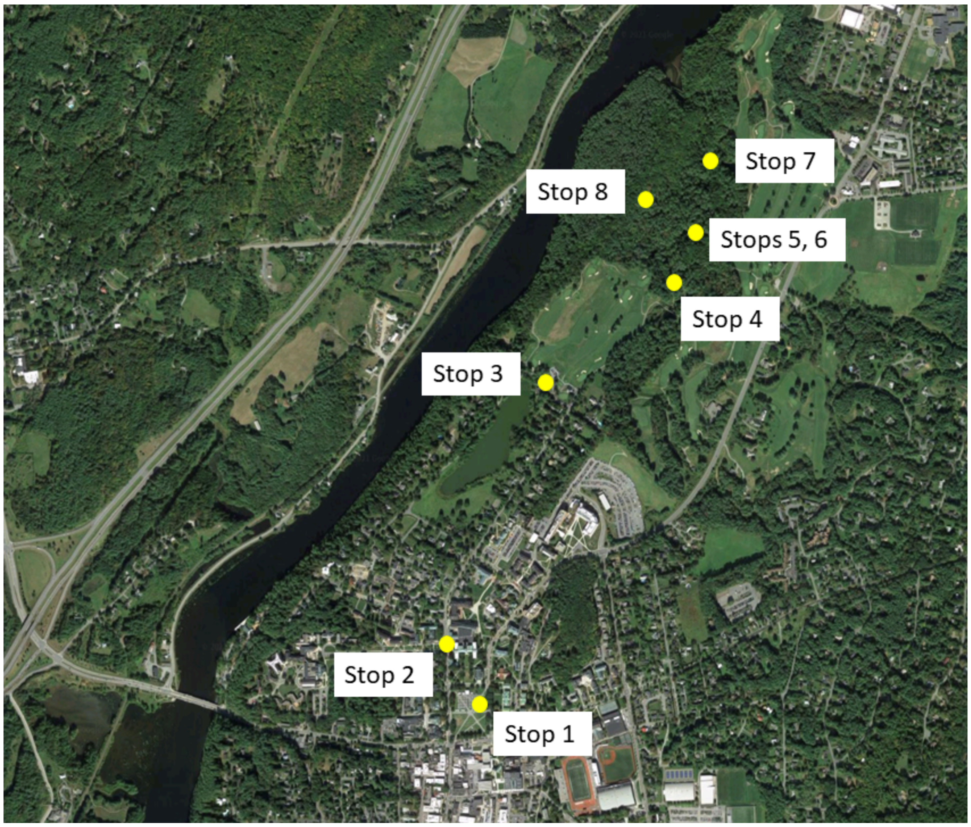

Fig. 4. Satellite image of the Hanover, NH, area showing field trip stops.

Stop 1. The Dartmouth Green (167 m asl)

The flat topography of the Dartmouth Green and the fine-grained, laminated (i.e., varved) sediments revealed in building excavations indicate that it was the *floor* of Glacial Lake Hitchcock. The Glacial Lake Hitchcock shoreline (surface of the water) was ~200 m asl. This water level is marked by the transition from varve lake sediments (below lake level) to bedrock covered by till (above lake level). The old ski jump at Oak Hill marks a former shoreline of Glacial Lake Hitchcock.

For scale, Baker Tower is 38 m high. Thus, the top of Baker Tower would have been 5 m taller than the depth of Glacial Lake Hitchcock.

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Stop 2. House on the Corner of Webster Ave.

Glacial varves were exposed in the foundation of the house on the corner of Webster Ave. (Fig. 5). The excavation occurred when the house was being rebuilt after a fire destroyed the old house. This deposit is an example of the lake bottom sediments that extend across many of the "flat surfaces" around campus.

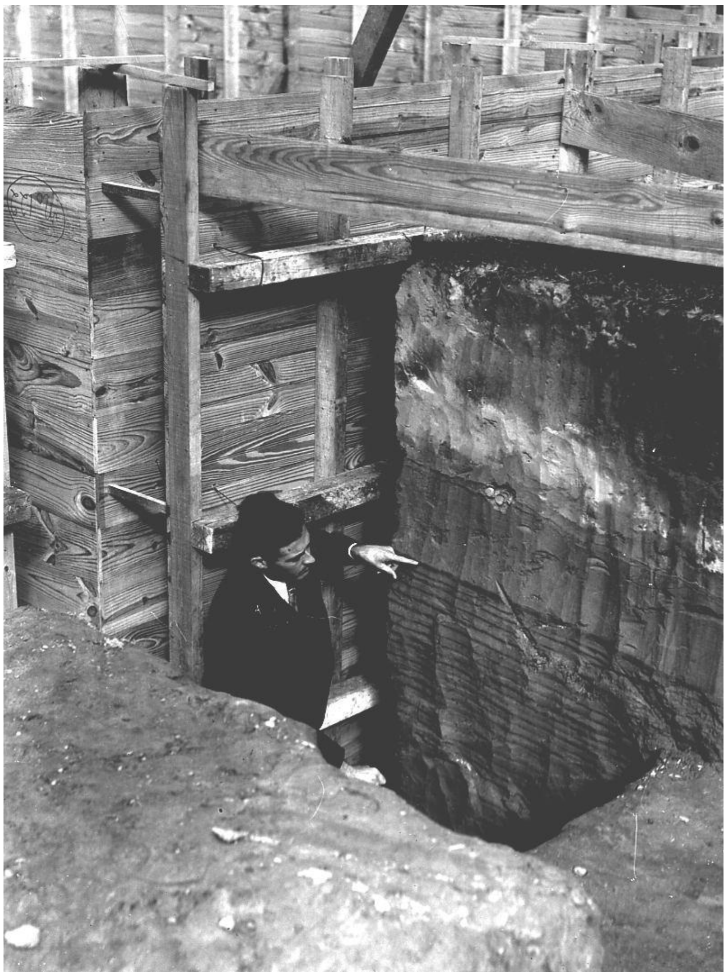

Fig. 5. The photo is from a glass-plate negative taken in 1933 by Dartmouth Geology Professor James W. Goldthwait. Pictured is Richard J. Lougee ('27), who studied varves in the Upper Connecticut Valley with Ernst Antevs and Dartmouth Professor Goldthwait in the 1920-30s. The image was provided by Woodrow B. Thompson ('68).

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Stop 3. Dartmouth Outing Club House on Occom Pond

Occom Pond is a **kettle pond**. This geologic term means that it is a body of water whose floor is within glacial sediments (Fig. 6). A kettle pond formed as a chunk of ice calved from the ice sheet margin and lodged in glacial sediments, forming a depression. If the chunk of ice melted in place, the depression was filled with water. Over longer periods of time, precipitation and groundwater would replenish the pond.

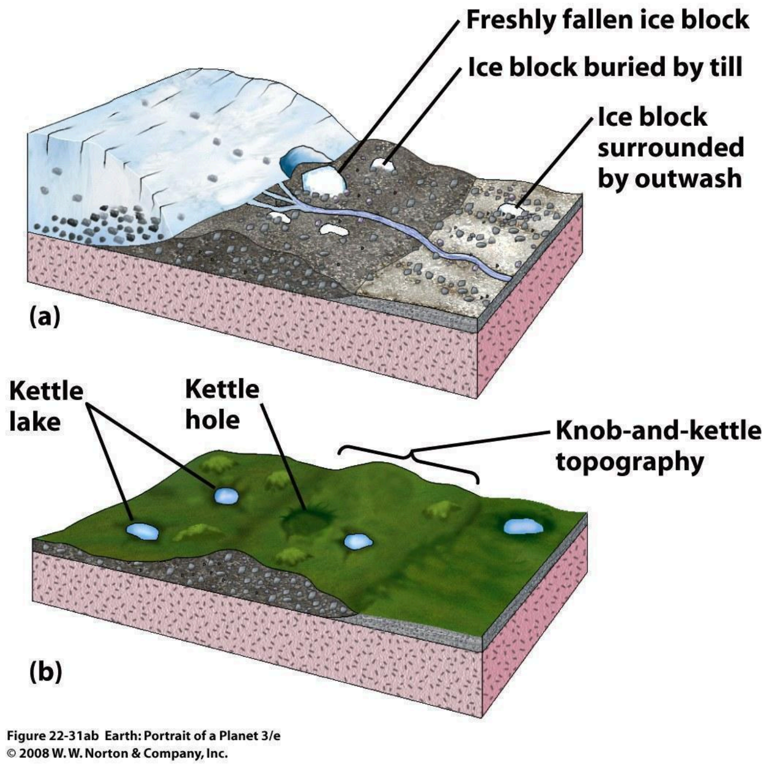

Fig. 6a. (Top) Image showing a receding ice sheet and ice marginal processes. Note the chunks of ice broken off from the margin, forming depressions in the glacial sediments.

Fig. 6b. (Bottom) Image showing the resulting landscape formed by the ice sheet in the top figure. Kettle lakes occupy depressions formed by ice.

Images from Marshak (2009).

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Fig. 6c. Google Earth image of Occom Pond.

Stop 4. Glacial Lake Hitchcock Varves in Girl Brook Valley

Exposures of glacial varves are visible in the Girl Brook valley walls (Fig. 7a-c).

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Fig. 7a. Example excavation along the valley walls of Girl Brook in Pine Park.

Fig. 7b. Closeup of the same exposure (Fig. 7a). Layers are varves (best visible in the upper left).

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Fig. 7c. Up-close view of the sediments in the excavation along the valley walls of Girl Brook in Pine Park. Note mm scale laminations of clay and silt.

Notes and observations from the varved sediments (Fig. 7a-c):

a) The grain size of the sediment that makes up the light colored varves (coarse silts and fine sands).

b) The grain size of the sediment that makes up the dark colored varves (silt and clay).

c) Varve thickness changes with depth (thinning upward). This pattern is associated with ice retreat, where the retting ice front (sediment source) gets further from the location of deposition.

e) Consider, what materials might be below the varves in Girl Brook (till with bedrock below).

<u>Stop 5. Girl Brook Stream Processes</u>

Girl Brook occupies a deep valley between the golf course and the Connecticut River. This valley formed as the stream **downcut** through the underlying glacial sediments to its base level. We will walk into the valley, follow Girl Brook and examine some modern stream processes.

Looking at the stream channel there are many modern processes (locations of deposition and erosion) that can be observed.

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Stop 6. Mass Movement: Soil Creep and Landslides

Notice the bent tree trunks along the slopes of Girl brook valley (Fig. 8). Trees typically grow skyward to maximize their access to sunlight. We will consider what processes might be at work on these hillslopes to cause bent trunks. The soft sediments are also prone to slumping (Fig. 9).

Fig. 8. The trees in the photo to the right show bent trunks. This phenomenon is commonly observed on steep, soil-covered hill slopes.

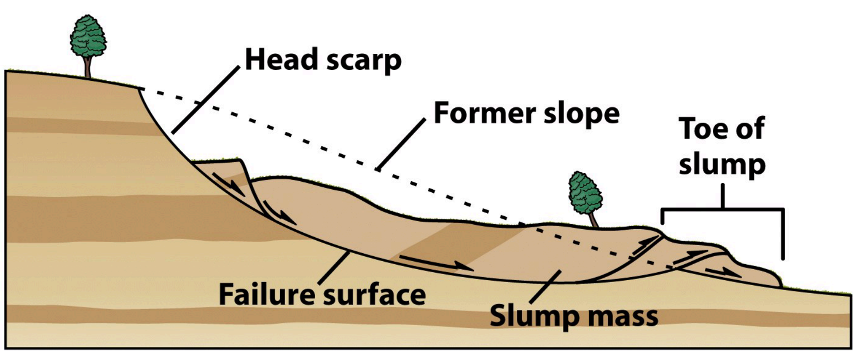

Fig. 9. Cartoon of a landslide known as a *slump*, where land moves downhill as a coherent mass.

Image from Marshak (2009).

Stop 7. Esker Sediments

We see an outcrop that shows significant change in the sedimentology of the Girl Brook valley walls. These sediments are characteristic of an *esker*, the filling of a tunnel that once existed and 0drained water beneath an ice sheet (Fig. 10). Water flowing below the ice sheet usually has a high discharge (remember the definition of "Q" from the lecture on streams).

Occom Ridge is an esker. We will first examine the sedimentology of this "outcrop" and then we will examine its morphology in Stop 8.

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Note: the esker sediments (sand and gravels) are much coarser grained than the varved sediments (silt and clay). This indicates a different transport mechanism (running water) for this higher energy environment.

<u>Stop 8. Occom Ridge Esker</u>

Occom Ridge is an *esker* (Fig. 10). Eskers often appear to adopt the morphology of a stream channel as they mark sediment flow in a tunnel at the base of an ice sheet. However, instead of forming a channel, eskers form long deposits of sediment ridges parallel to the direction of ice sheet flow. Figures 11 – 13 show the topography, including the esker ridge. Figure 14 is a representation of the deposits in cross section.

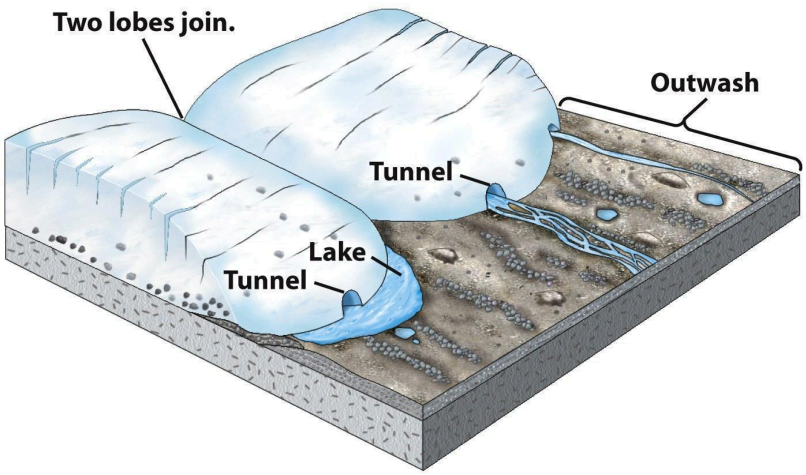

Figure 22-28a Earth: Portrait of a Planet 3/e

Fig. 10. (Top) Image showing a receding ice sheet and ice marginal processes. Note the proglacial lake forming and the stream emanating from a tunnel at the ice sheet margin.

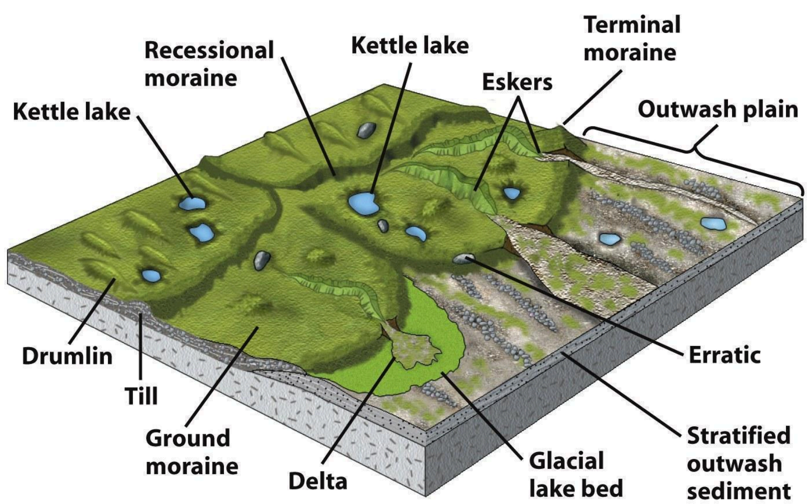

Figure 22-28b Earth: Portrait of a Planet 3/e

(Bottom) Image showing the resulting landscape formed by the ice sheet in the top figure. Geomorphic features to note are a glacial lake bed and eskers.

Images from Marshak (2009).

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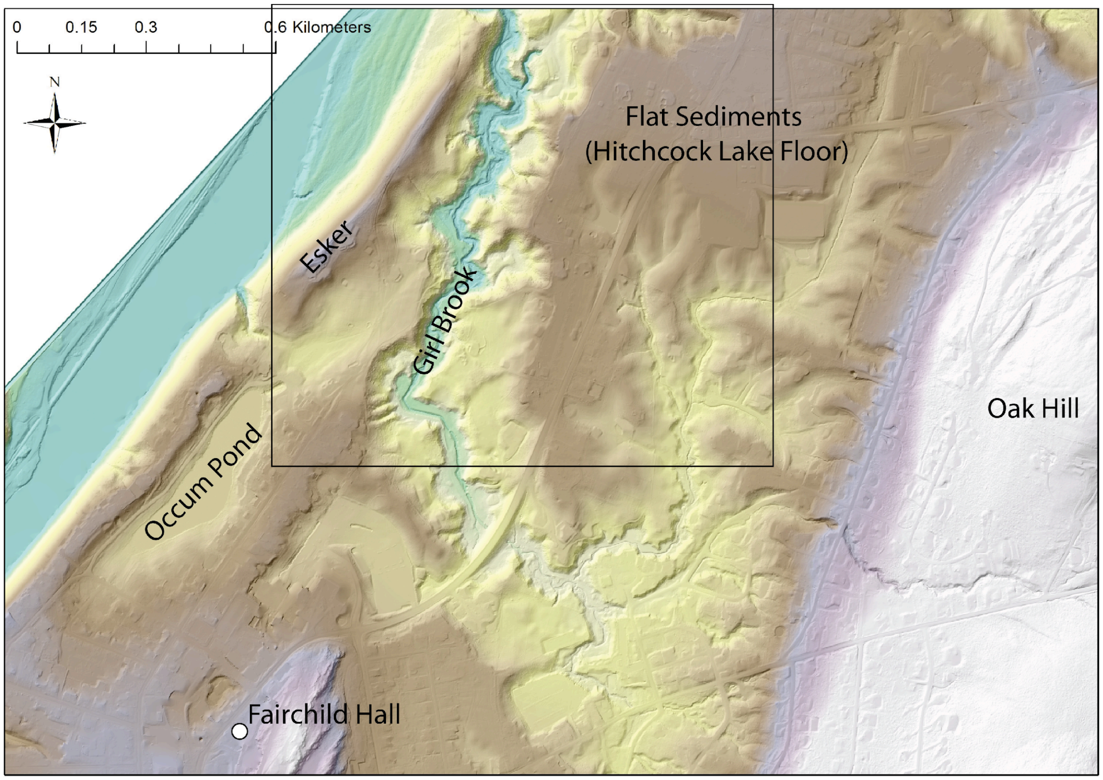

Fig. 12. Shaded relief LIDAR image of the Hanover area. Box shows the extent of Fig. 13.

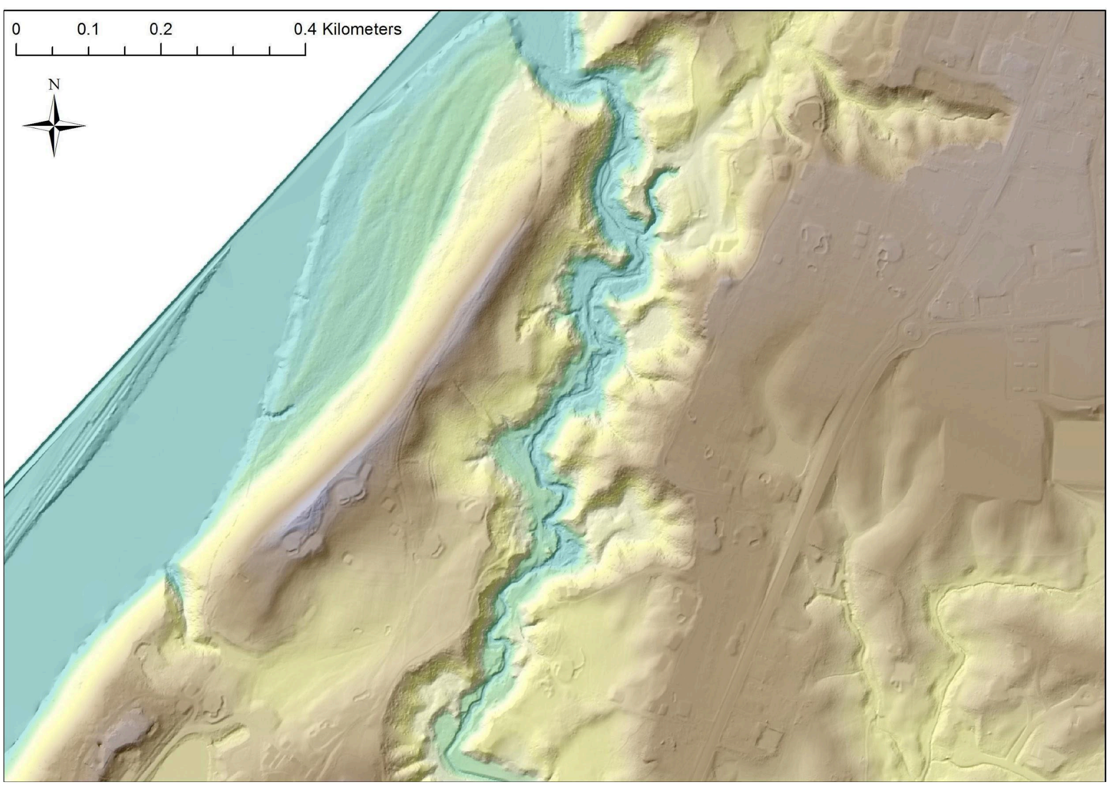

Fig. 13. Shaded relief LIDAR image of the Girl Brook and Occom Ridge area.

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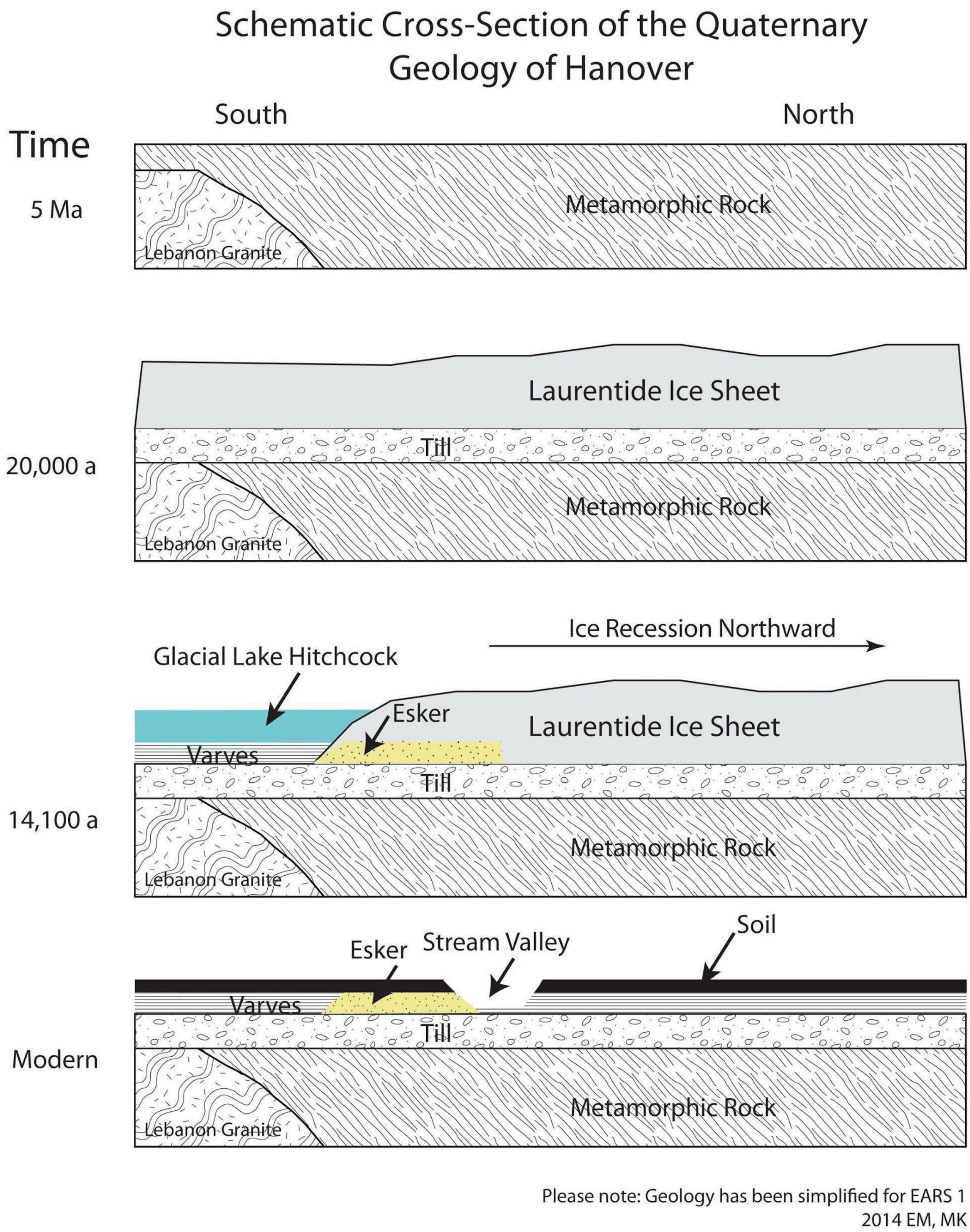

Figure 14. Schematic cross-section of the Hanover area from south to north. Images show the landscape evolution influenced by cover by the Laurentide Ice Sheet and, subsequently, Glacial Lake Hitchcock.

Name__________________

References

Dyke, A., 2004. An outline of North American Deglacaition with Emphasis on Central and Northern Canada *in* (Ehlers, J., and Gibbard, P.L., Eds.) *Quaternary Glaciations – Extent and Chronology, Part II*. Elsevier, Amsterdam, the Netherlands, 373-424.

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Ridge, J.C., 2008. "The North American Glacial Varve Project", http://ase.tufts.edu/geology/varves), Sponsored by the National Science Foundation and the Geology Department of Tufts University, Medford, MA.

Ridge, J.C., 2004. The Quaternary Glaciations of Western New England with Correlations to Surrounding Areas, *in* (Ehlers, J., and Gibbard, P.L., Eds.) *Quaternary Glaciations – Extent and Chronology, Part II*. Elsevier, Amsterdam, the Netherlands, 169-200.

U.S. Geological Survey, 1988. Hanover Quadrangle, 1:24,000. 7.5 Minute Series Photo revised 1996. Reston, VA: United States Department of the Interior.

Additional Figures for Discussion and Activity

General Stratigraphy From Lake Sediment Cores within the Glacial Lake Hitchcock basin:

Lake sediment cores from within the Glacial Lake Hitchcock basin often have the following general stratigraphy:

1) Till - deposited from the ice sheet

2) Basal varves – thick varves deposited near the retreating ice front

3) Varves - in a thinking sequence that corresponds with ice retreat.

4) Gray silt and clay - transitional sediments perhaps associated with distal ice and post glacial landscape stabilization.

5) Organic rich sediments - onset of organic deposition more analogous to modern lake conditions.

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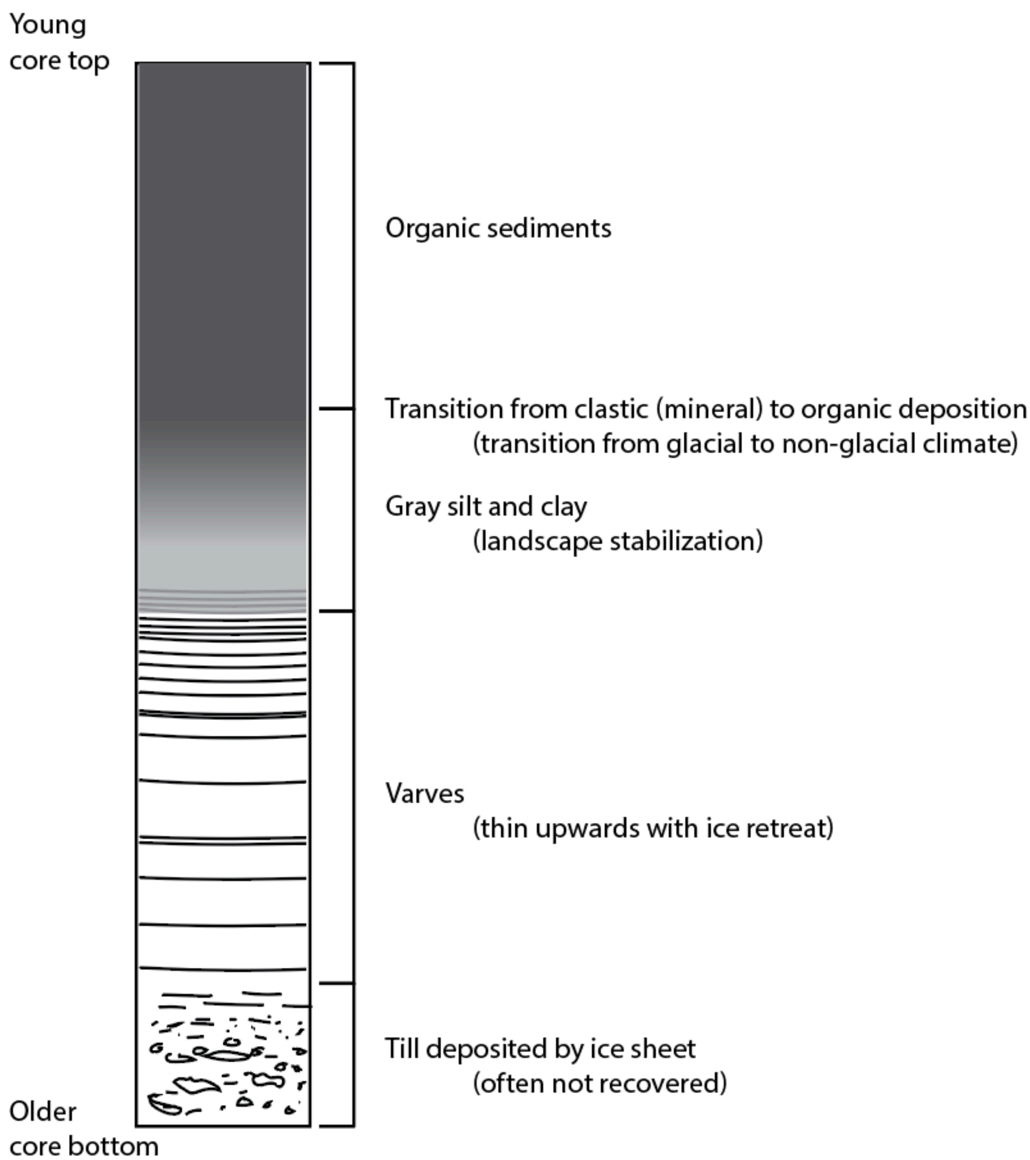

Young
core top
Organic sediments
Transition from clastic (mineral) to organic deposition
(transition from glacial to non-glacial climate)
Gray silt and clay
(landscape stabilization)
Varves
(thin upwards with ice retreat)
Till deposited by ice sheet
(often not recovered)
Older
core bottom

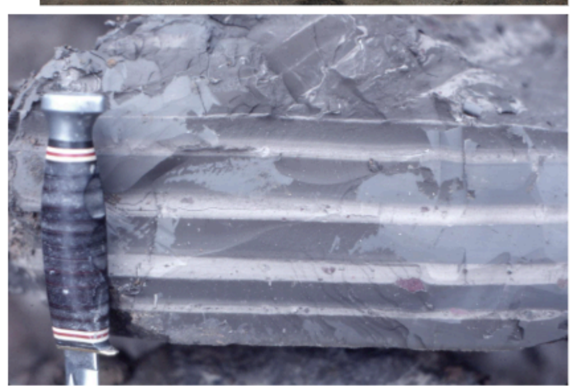
Name__________________

Varve Background Figures:

Additional figures about varves (Materials from Dartmouth EARS 1 and Ridge 2008).

Glacial varves (deposited in pro-glacial lakes)

- Varve – an **annual** sediment layer
  - Form due to seasonal changes during one year
- **Glacial varve**– forms in a pro-glacial lake
  - Summer (light-colored layer) - Sand/silt deposited when there are currents in the lake and waves on the lake surface (water is higher energy)
  - Winter (dark-colored layer) - Clay deposited when there is no meltwater from the glacier and the lake is covered with ice (water is lower energy)



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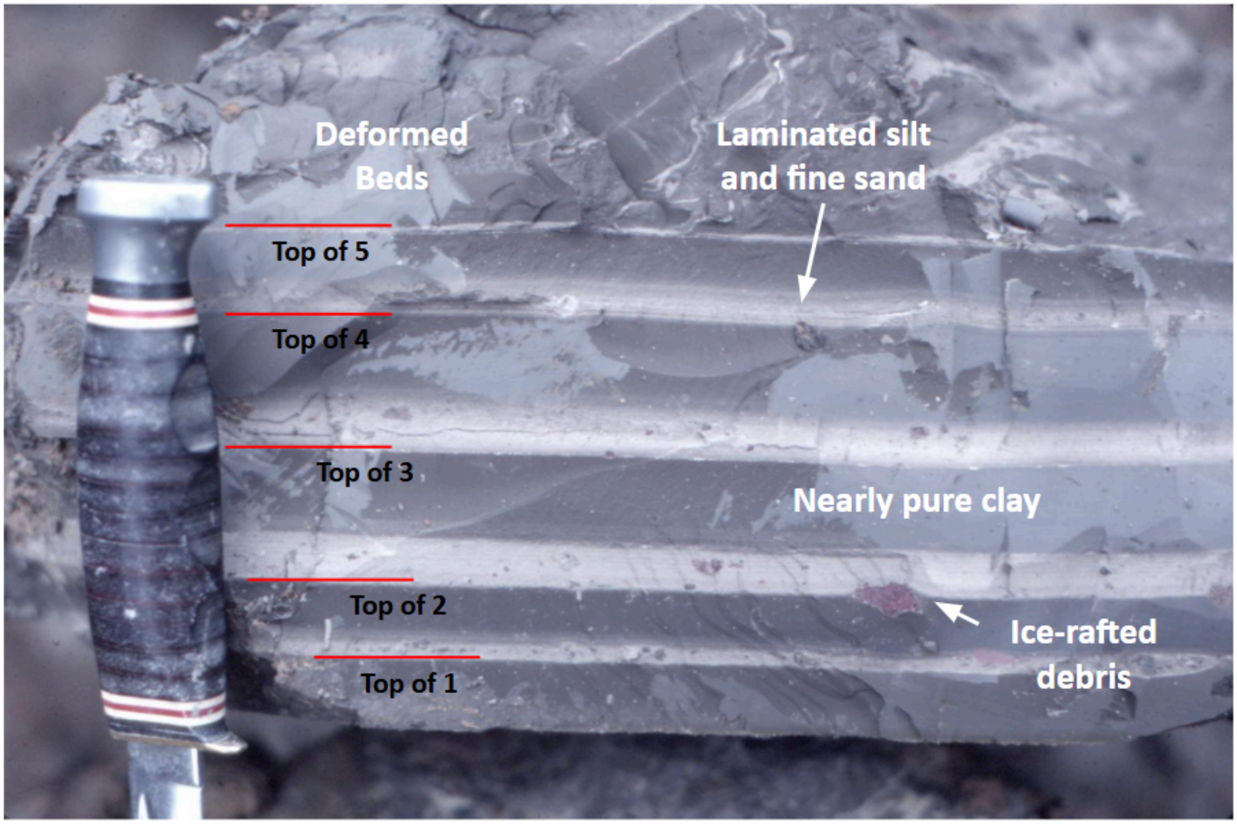
GLACIAL VARVE RECOGNITION



Site 946, Herkimer, NY (western Mohawk Valley)

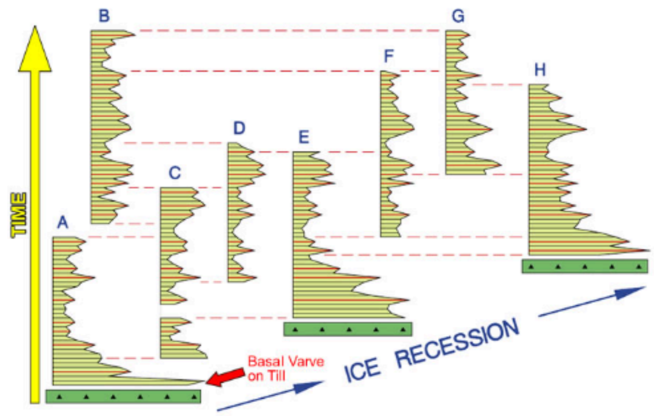
Name___________________

Interpret time/rate of deglaciation

- Time of deglaciation from:
  - Varves deposited on till, gravel or bedrock
  - Very thick basal varves = ice-proximal environments

- New England varves become progressively younger northward

- Can calculate rates of ice recession



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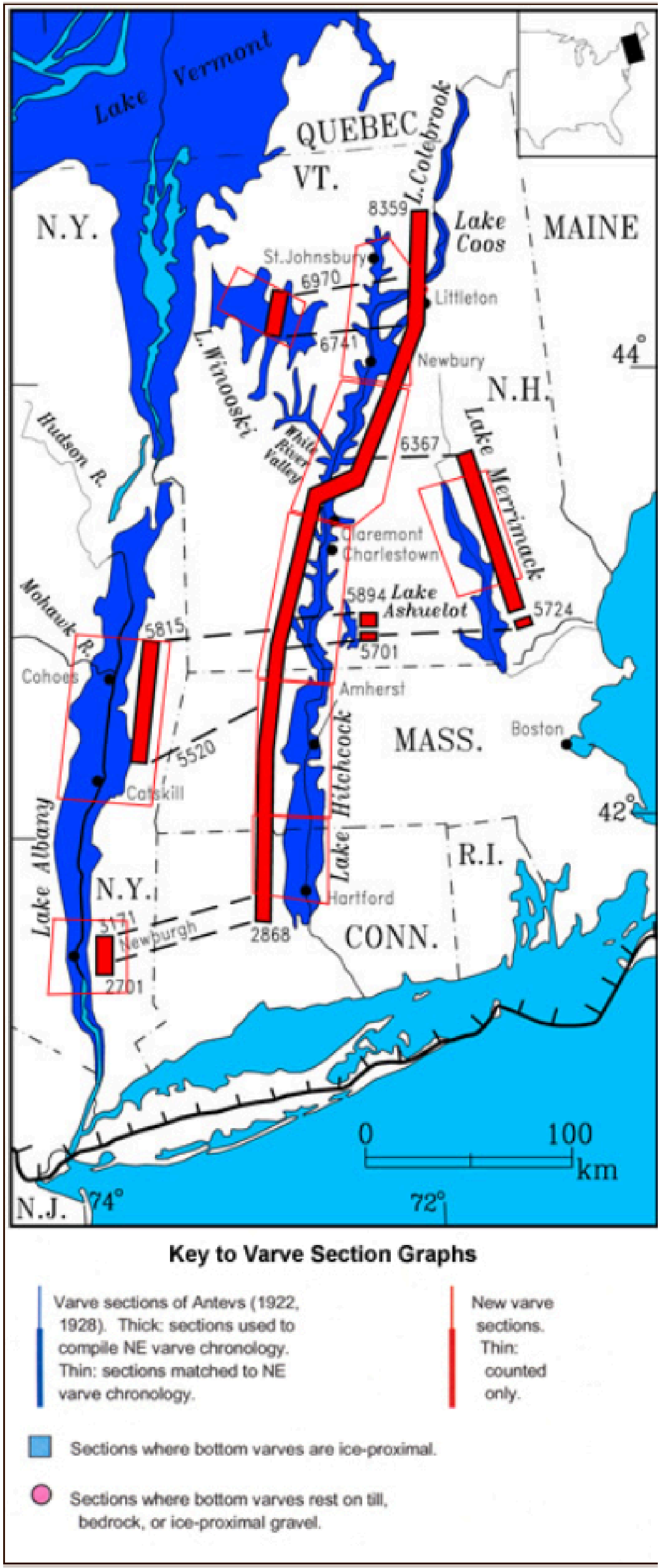
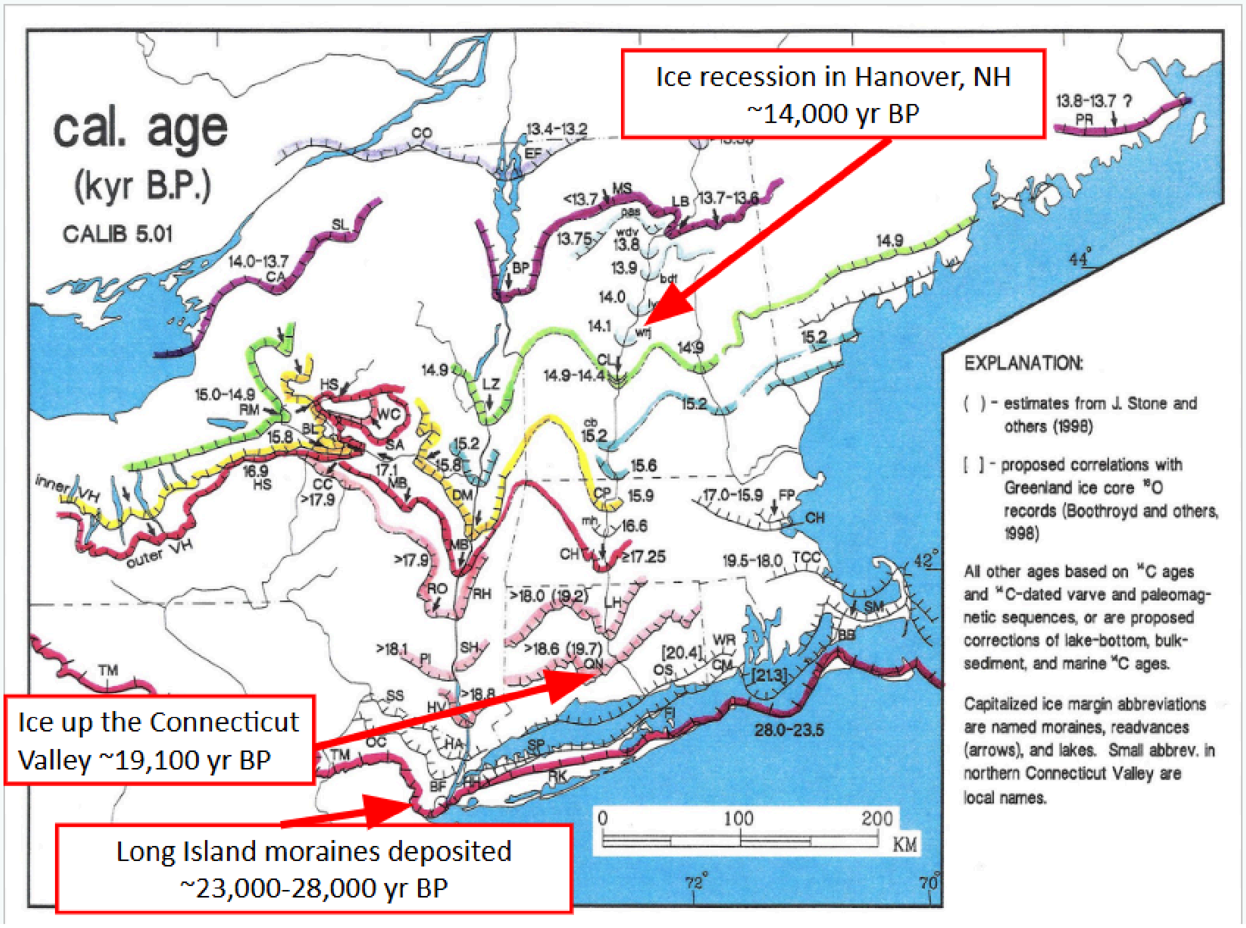


Lake Vermont
QUEBEC
VT.
N.Y.
L.Colebrook
8359
Lake Coos
MAINE
St.Johnsbury
6970
Littleton
6741
Newbury
44°
N.H.
L. Winooski
White River Valley
6367
Lake Merrimack
Hudson R.
Claremont
Charlestown
5894
Lake Ashuelot
5724
5701
Mohawk R.
5815
Cohoes
Amherst
MASS.
Boston
5520
Catskill
Lake Hitchcock
42°
Lake Albany
R.I.
N.Y.
Hartford
3171
Newburgh
2868
CONN.
2701
0
100
km
N.J.
74°
72°
Key to Varve Section Graphs
Varve sections of Antevs (1922, 1928). Thick: sections used to compile NE varve chronology. Thin: sections matched to NE varve chronology.
New varve sections. Thin: counted only.
Sections where bottom varves are ice-proximal.
Sections where bottom varves rest on till, bedrock, or ice-proximal gravel.

Name__________________



cal. age
(kyr B.P.)
CALIB 5.01
Ice recession in Hanover, NH
~14,000 yr BP
Ice up the Connecticut
Valley ~19,100 yr BP
Long Island moraines deposited
~23,000-28,000 yr BP
EXPLANATION:
( ) - estimates from J. Stone and others (1998)
[ ] - proposed correlations with Greenland ice core ¹⁸O records (Boothroyd and others, 1998)
All other ages based on ¹⁴C ages and ¹⁴C-dated varve and paleomagnetic sequences, or are proposed corrections of lake-bottom, bulk-sediment, and marine ¹⁴C ages.
Capitalized ice margin abbreviations are named moraines, readvances (arrows), and lakes. Small abbrev. in northern Connecticut Valley are local names.
0
100
200
KM

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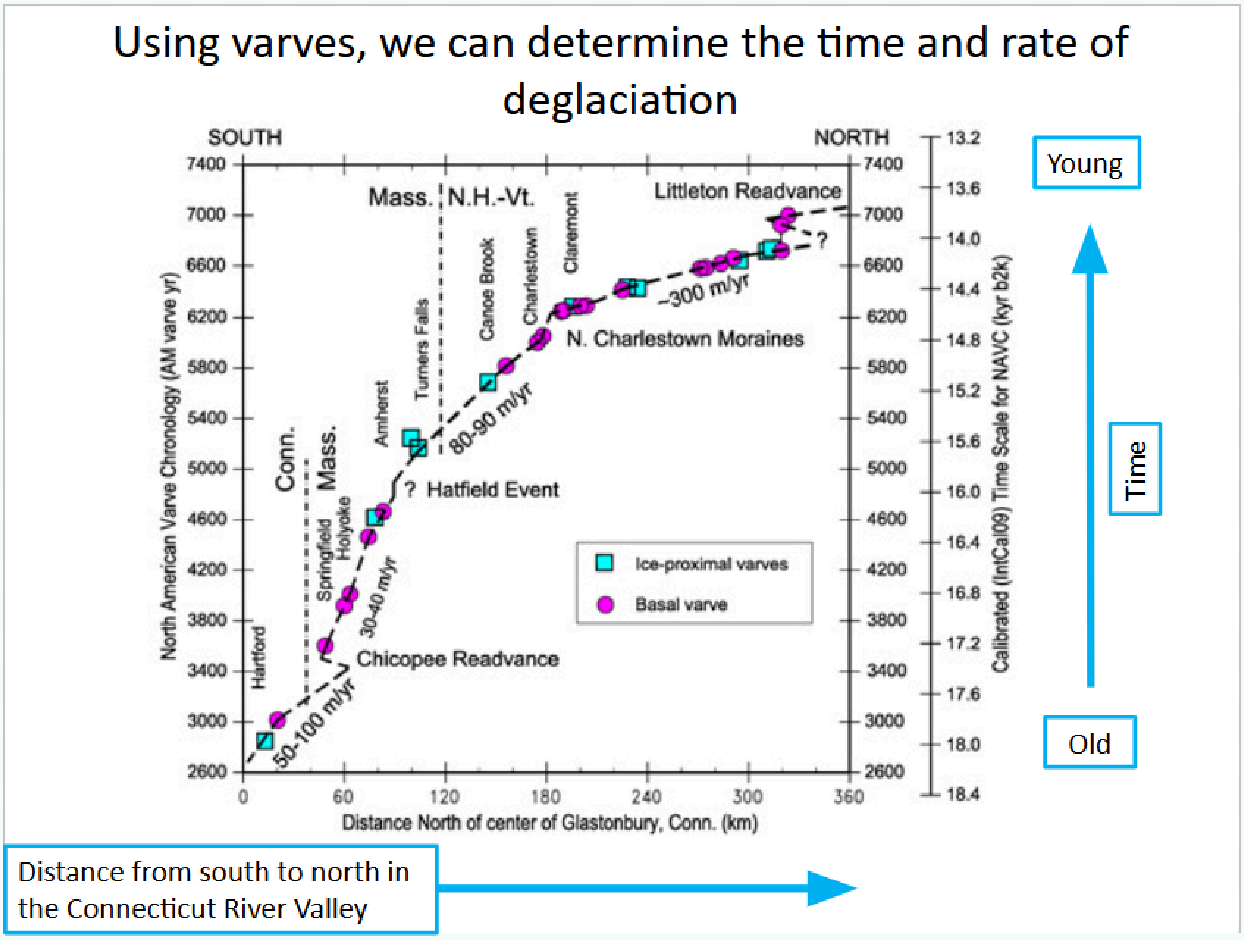
Using varves, we can determine the time and rate of deglaciation
SOUTH
NORTH
North American Varve Chronology (AM varve yr)
Calibrated (IntCal09) Time Scale for NAVC (kyr b2k)
Distance North of center of Glastonbury, Conn. (km)
Conn.
Mass.
N.H.-Vt.
Hartford
Springfield
Holyoke
Amherst
Turners Falls
Canoe Brook
Charlestown
Claremont
Littleton Readvance
N. Charlestown Moraines
? Hatfield Event
Chicopee Readvance
50-100 m/yr
30-40 m/yr
80-90 m/yr
~300 m/yr
Ice-proximal varves
Basal varve
Young
Time
Old
Distance from south to north in the Connecticut River Valley