Deglaciation in the Southeastern Laurentide Sector and the Hudson Valley – 15,000 Years of Vegetational and Climate History

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Introduction

In this field trip, we provide a review of the significant controversy concerning the timing of deglaciation in the Hudson and Wallkill Valleys. We outline the differences in methodology and chronology with a circular route throughout the Hudson and Wallkill valleys. We begin the trip at Lake Mohonk near New Paltz led by Kirsten Menking and Dorothy Peteet, then continue to the "black dirt" region of the Wallkill Valley where John Rayburn has contributed a new GIS model of deglaciation in the Wallkill Valley and Guy Robinson will review the history of fossil mammals, including mammoths. From this point we travel southeast to a rare exposure of glaciolacustrine beds on the west side of the Huson River, described by Byron Stone and John Rayburn, and on to Croton Marsh at Croton Point, New York where Dorothy Peteet will review the marsh histories of the region.

A recent review of literature relating to the last glacial recession in the Hudson Valley indicates that the timing of deglaciation is very controversial (Peteet et al., 2006; Peteet, in review; Balco et al., 2006; Balco et al., 2009; Schaefer, 2007). Some questions to consider:

1) How does timing of new lake basal dates at the margin of the ice (Staten Island) compare with sites to the north and inland (ie. Mohonk)?
2) What is the vegetational history of the region and how does it compare with Deevey's classical southern New England stratigraphy?
3) What is the latest model of the deglaciation of the Wallkill Valley?
4) What have the Hudson marshes added to our understanding of the vegetation and landscape history, particularly in the last few millennia?

I. Review of Hudson Valley regional glacial history – a continuing controversy

Bulk C-14 Ages

Muller and Calkin (l993) summarized the deglaciation history of southern New York, using bulk chronologies to indicate deglaciation by 18,750 ^{14}C (23 -24 kyr). However, these authors remarked on the weak chronostratigraphic framework for the region. From the New Hampton Bog near Wallkill, NY, Connally and Sirkin (1986) argued for ice retreat at 17.2 ^{14}C (20 kyr) based on an extrapolated age for basal inorganic sediments. These earliest glacial studies in the region (Sirken, l982; Connally and Sirkin, l986) argued for general deglaciation approximately 18 ^{14}C (21-23 kyr), again calculated from extrapolated sedimentation rates below bulk ^{14}C dates. In contrast, from bulk-dated sites near the glacial margin in Pennsylvania, Crowl (1986) argued for a somewhat younger glaciation (15 ^{14}C (18-18.5 kyr) but Connally and Sirken (1986) continued to argue for the older timing for ice recession based on Cotter's (1983) 18.6 ^{14}C (23.3 kyr) date from Francis Lake and other bulk dates. The detailed surficial geologic maps of adjacent northern New Jersey (Stone, Stanford, and Witte, 2002) and Connecticut and Long Island Sound basin (Stone and others, 2005) incorporated these older postglacial dates as constraining ages on the early deglaciation of the region. The duration of the early glacial recession in New Jersey and Connecticut further was correlated with detailed stratigraphic frameworks that encompass recessional moraines, voluminous deposits of numerous glacial lakes in all of the valleys, and successive ice-marginal deltaic morphosequences that trace the recession of the ice margin in each glacial lake. These maps also utilize the thickness and known/inferred number of glacial varves in the major glacial lakes, and the dated postglacial deposits in the valleys to estimate the date of ice recession. This older deglaciation chronology has been the accepted version of deglaciation that glacial stratigraphers, and varve and cosmogenic investigators have utilized.

AMS C-14 Ages

In contrast to this relatively early age for deglaciation, more recent AMS dating of basal sediments from lake/bog sites suggest a substantially younger age for initial accumulation of postglacial sediments, and, perhaps, deglaciation throughout at 12.5 ^{14}C (15 kyr) (Peteet et al., 1990; 1993; 2006; Peteet et al., in review). A suite of 10 lakes ranging from Linsley Pond, Conn. to Uttertown Bog in western NJ indicate a remarkably consistent pattern of tundra and/or spruce colonization that followed ice retreat throughout the region. Uncertainties in using basal-sediment dates and earliest pollen-succession chronologies for deglaciation include whether ice blocks remained in lakes and/or whether a significant migration lag could have taken place.

Cosmogenic Ages

The oldest ^{10}Be ages from Martha's Vineyard indicate a maximum glacial extent age of about 23.2 kyr, and formation of Cape Cod recessional moraine complex forming 18.8 kyr (Balco et al., 2002). The initiation of the deglaciation represented by the eastern Connecticut moraines occurred about the same time as Cape Cod, at 18.5-19 kyr. ^{10}Be dating on glacial erratics and bedrock from NYC is interpreted to indicate deglaciation about 18 kyr (Schaefer et al., 2007). However, more recently, Balco et al. 2009 utilized varve chronologies from New England to recalculate the deglacial age for the terminal moraine in New Jersey at about 25 kyr. Uncertainty in the ^{10}Be ages lies in production rate assumptions, geomorphic stabilities of boulders and outcrops, and the potential for inheritance in the erratics dated.

Varve Ages

The confirmation and rebirth of the New England varve chronology by Ridge et al. (2004) has resulted in a deglaciation scenario with an early chronology of deglaciation defined as 20-25 ^{14}C (23.7-28 kyr). Ridge has added floating varve chronologies from the New Jersey-New York-Connecticut region to the existing dated chronology further north in Vermont and derives this relatively old age which is more in agreement with bulk ^{14}C chronology but is 8-12 kyr older than the AMS chronology.

II. Mohonk region site descriptions and vegetation and climate history

Site 1 – Lakes Mohonk and Minnewaska

Lakes Minnewaska and Mohonk lie atop the Shawangunk Mountains in southeastern New York, parallel ridges of Silurian-age quartz pebble conglomerates and quartz sandstones (Shawangunk Formation) that are part of the southeasternmost ridge of the Appalachian Mountains (Bernet et al., 2007; Macchiaroli,

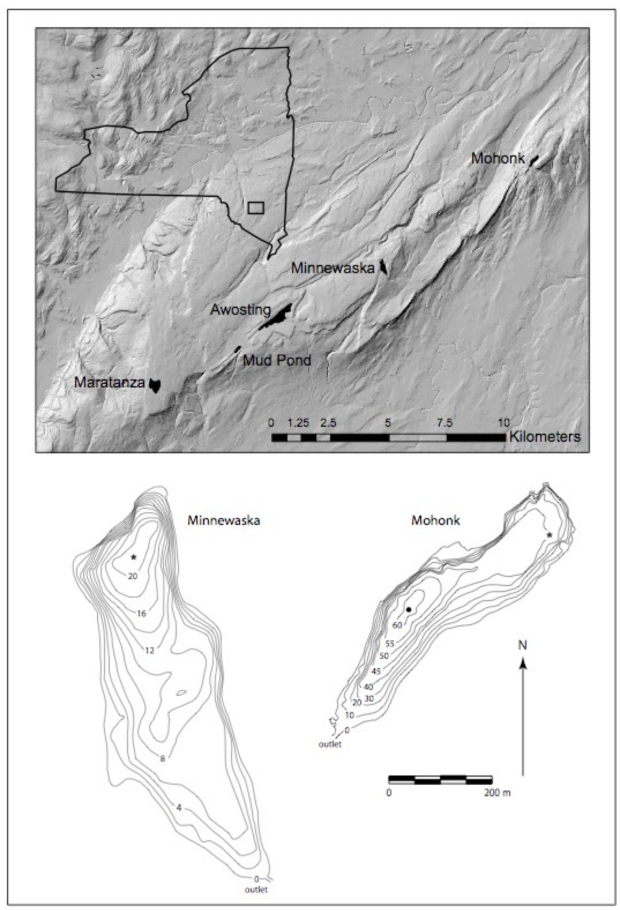

Figure 1. Map of Shawangunk ridge and bathymetry of Mohonk and Minnewaska.

1995). During the late Pleistocene, ice from the Hudson-Champlain lobe of the Laurentide ice sheet covered the mountains to a depth of ~600 m, and many glacially polished and striated surfaces are found throughout the range. Five lakes (collectively called the Sky Lakes), produced by glacial plucking and deepening of tectonically fractured bedrock, lie in a NE-SW trending line along the ridge crest (Figure 1).

None of the lakes have inflow streams, thus all are fed primarily by precipitation falling on the range, with very minor groundwater inflow (Coates and others, 1994). The lack of inflow streams to each lake means that sedimentation rates are low and that deposition is dominated by the annual cycle of deciduous trees and in situ aquatic production. Modern vegetation in the Shawangunks includes numerous pitch pine barrens, dwarf pine plains, and a variety of deciduous hardwood and mixed deciduous/conifer communities (Kiviat, 1988). Vegetation type is controlled largely by local variations in glacial till thickness, wind stress, and slope.

Methods

Sediment cores were extracted from Lakes Minnewaska (Feb. 1999) and Mohonk (Feb. 2004) in winter using a 7-cm diameter, 1.5-m-long Livingston corer dropped through a hole cut into the frozen lake surface. Cores were split and described the day after extraction followed by sampling. One cubic centimeter samples for carbon content and isotopic analysis were taken every 3-5 cm along each core. Samples were treated with weak HCl to remove any carbonate, rinsed in deionized water, dried at 60 °C, ground with a mortar and pestle, and stored in a desiccator prior to analysis. Organic carbon contents were measured by coulometry. Carbon and nitrogen isotopic values were determined using a Carlo Erba NA 1500 Series II NC elemental analyzer connected to a GV Instruments Optima stable isotope mass spectrometer at the University at Albany in Albany, NY. An additional 1 cm^3 sample was taken for pollen and charcoal analysis. Half of this sample was dried and weighed to determine dry bulk density. The remaining half

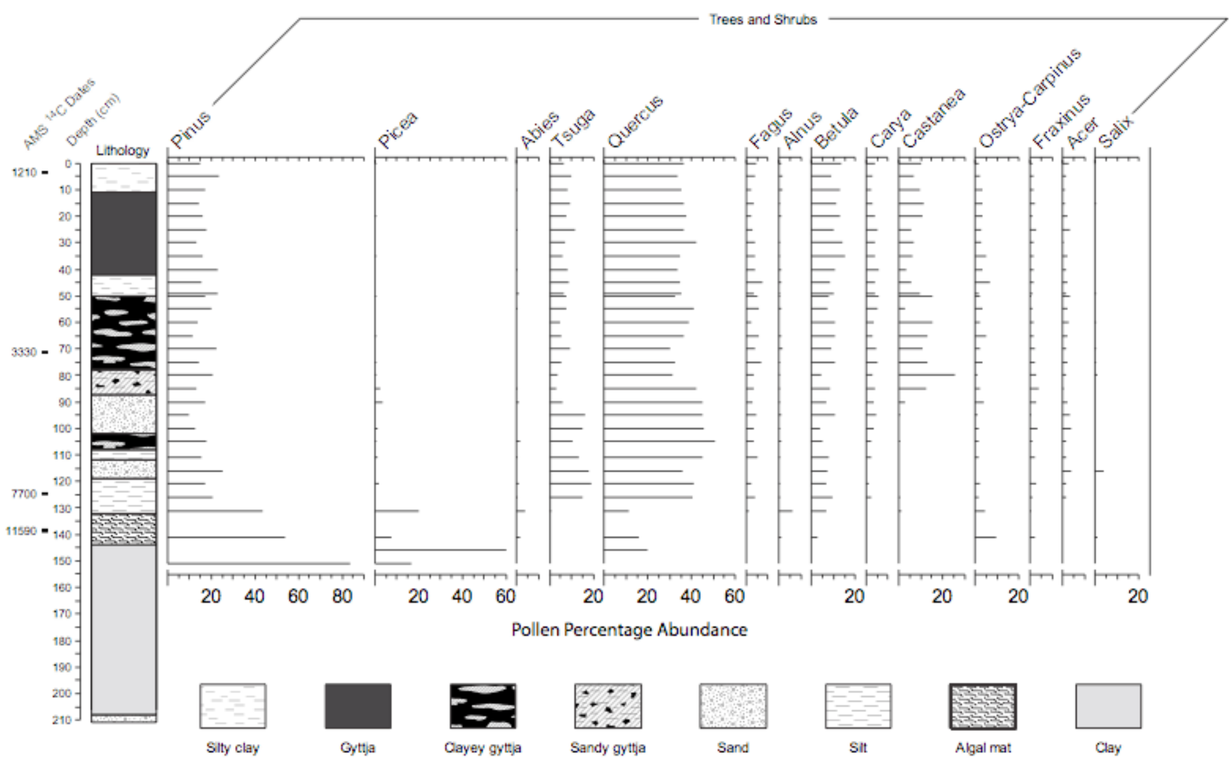

Figure 2. Lithology, pollen and spore percentages from Lake Mohonk. See discussion below (Kirsten Menking, analyst).

was washed through a 125-micron sieve to separate out plant fragments and macroscopic charcoal. Standard palynological and macrofossil techniques were utilized (Faegri and Iverson, 1975; Watts and Winter, l966).

Lake Mohonk

The Mohonk Lake core (Figure 2) measures 2.1 m in length and was taken from a water depth of ~14 m. The core bottoms in sand, above which lies 0.6 m of gray organic-poor clay. An 0.1-m-thick mat of an unidentified aquatic plant caps the clay at 138 cm depth in the core and dates to 11,590 ^{14}C yr b.p. Above this plant mat lies a mixture of sand, silty clay, clayey gyttja, sandy gyttja, and gyttja layers varying in thickness from approximately 0.05 to 0.3 m. Organic carbon content in the core varies from nearly 0% in the basal sand and clay units to a maximum of 20% in the algal mat. Above the algal mat organic carbon declines to values between 0 and 16%, with sand units showing low values and gyttja-rich layers showing higher values. Carbon isotopes on organic matter show little variation with depth with the exception of the plant mat, which is nearly 10‰ more negative than the rest of the organic matter in the core. Core sediments are nearly devoid of pollen below 1.55 m depth, so the pollen diagram shown in figure 2 is terminated at that depth.

Lake Minnewaska

The Lake Minnewaska (Figure 1) core measures 2.4 m in length and was taken in a depth of ~20 m of water. The bottom ~0.5 m of the core consists of layered silt, sand and clay, with individual layers a few mm thick. Above this unit lies ~0.5 m of uniform gray clay. Both of these units are devoid of organic matter, and neither contains much pollen. The top 1.4 m of the core is organic rich, with carbon contents measuring between 8 and 32%. The transition from sediments devoid of organic matter to organic-rich sediments occurs abruptly at a depth of 140 cm in the core and has been dated at 14.5 ^{14}C kyrs b.p. Organic carbon content climbed from <1% to >20% of sediment mass by 10.1 ^{14}C kyrs b.p. coincident with a 7‰ shift to more negative values of δ^{13}C, indicating that this oligotrophic, rainwater fed lake required 4500 years to acquire a fully developed aquatic ecosystem. Within the organic rich zone occur several large oscillations in carbon content and δ^{13}C, possibly reflecting changes in the relative importance of terrestrial versus aquatic vegetation. As in the Mohonk core, the Minnewaska sediments are devoid of pollen below 140cm.

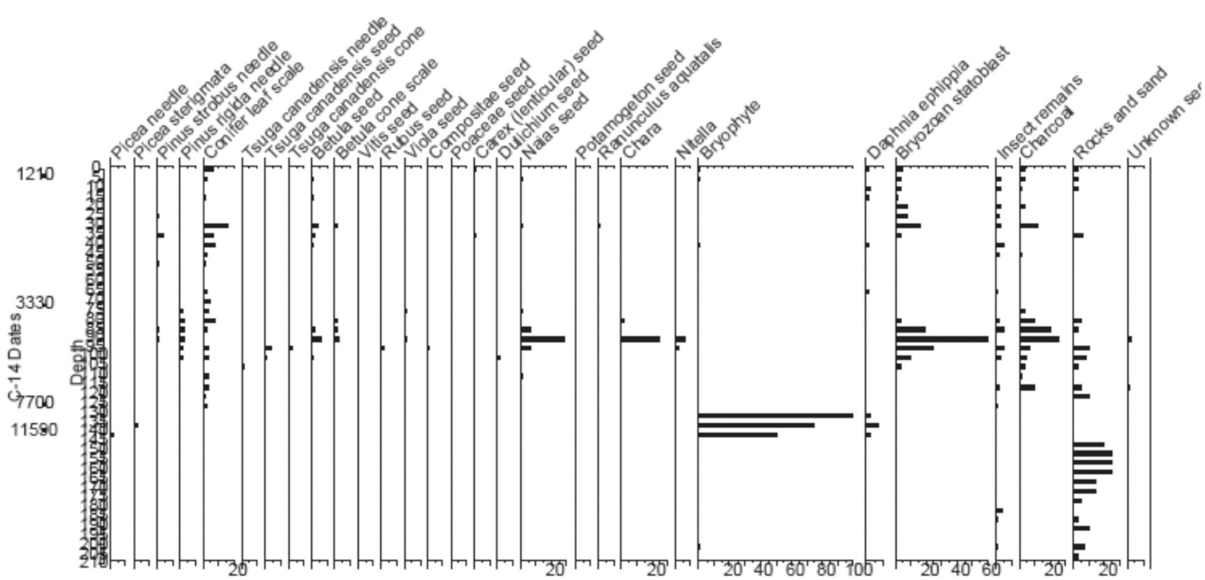

Figure 3. Macrofossil and charcoal diagram from Lake Mohonk (D. Peteet, analyst).

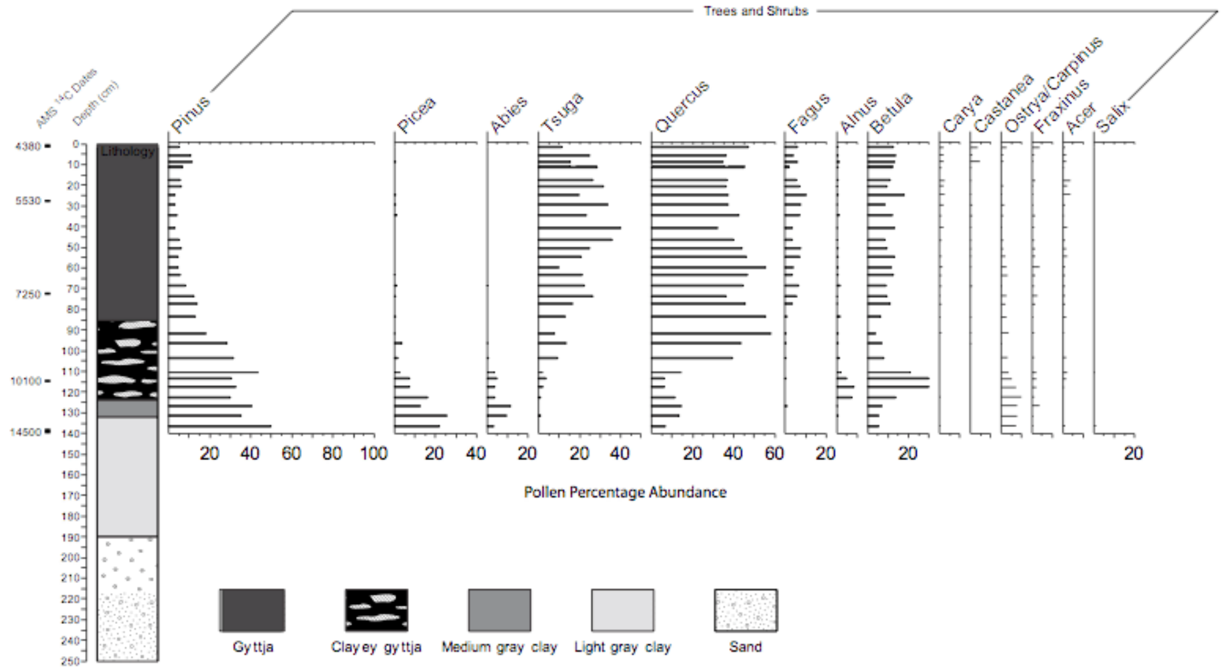

Figure 4. Minnewaska lithology, pollen and spore percentage diagram (Kirsten Menking, analyst).

Mohonk and Minnewaska pollen and plant macrofossil stratigraphies

The layered sands and silts at the base of the Minnewaska core resemble seasonal varves, and this combined with the lack of organic matter and pollen in the basal sediments of both cores suggests that both lakes had inflow streams during deglaciation. Deposition of clay thereafter probably indicates loss of the inflow streams and very local wind and rain erosion that mobilized silt and clay sized particles in the unstable landscape surrounding the lakes. This style of sedimentation ended with the arrival of forest vegetation, when gyttja deposition commenced.

Both the Minnewaska and Mohonk cores show the classical northeastern pollen sequence made famous by workers such as Deevey (1939) and Davis (1969). Spruce (*Picea*) and fir (*Abies*) pollen at the base of each core declined abruptly shortly after 10 ^{14}C kyr b.p. and were replaced by pine (*Pinus*), oak (*Quercus*) and hemlock (*Tsuga*) as climate warmed following deglaciation. Relatively high amounts of alder (*Alnus*) and birch (*Betula*) between 110 and 125 cm depth in the Minnewaska core likely reflect the Younger Dryas cooling event (Peteet et al., 1990; Mayle et al., 1993). This event is not as readily apparent in the Mohonk core, though one sample at ~130 cm depth shows elevated alder pollen.

The top of the Minnewaska core dates to 4380 ^{14}C yr b.p., just after the hemlock decline noted in many northeastern pollen records and attributed by Davis (1981) to an arboreal pathogen outbreak around 4800 ^{14}C yr b.p. The beginning of the hemlock decline is evident in the Minnewaska core and still more convincing in the Mohonk core where hemlock pollen drops by a half to two thirds of its previous abundance at ~95 cm depth. Though we do not have a radiocarbon date on the timing of hemlock decline in the Mohonk core, simple interpolation based on a linear sedimentation rate between the 3330 and 7700 ^{14}C yr b.p. dates places an age of roughly 5000 ^{14}C yr b.p. at 95 cm, showing agreement with other records in the region.

Plant macrofossil analysis of the Mohonk core shows the presence of spruce needles in the basal gyttja. Pitch pine (*Pinus rigida*) needles, a pine adapted to fire, appear between 105 and 75 cm along with shallow aquatics such as waternymph (*Najas)*, resting spores of green algae stoneworts (*Chara*, *Nitella)* and abundant macroscopic charcoal.

These indicators all suggest drier conditions and fire. .

Foster et al. (2006) have recently questioned the pathogen explanation for hemlock decline in southern New England, calling instead on mid-Holocene drought as the primary driver for changes in forest composition. The charcoal and plant macrofossil data from the Mohonk core support this idea, which is given further credence by the sedimentology, which shows an interruption of clayey gyttja sedimentation in favor of poorly sorted sand deposition in the middle Holocene. We interpret this stratigraphy to represent destabilization of the landscape in the presence of frequent fires along with mass movements.

Site 2 - Rhododendron Swamp

Rhododendron Swamp measure 2.4 hectares and lies 275 m above sea level at the base of a 20 m conglomerate cliff southwest of Lake Mohonk. A 4-meter core was taken in 2002, using both a Livingstone piston corer and a Hiller corer for the top sediments. Rhododendron Swamp records a basal age of 12.5 ^{14}C (14.6 kyr) at 2.82 m depth, the base of the organic clay. Pollen and spore stratigraphy down to 118 cm (8000 ^{14}C years) is provided by a masters student at LDEO, Sage Markgraf, and ongoing pollen, spore, and macrofossil stratigraphy to the base of the core is in progress.

The Holocene stratigraphy provides some interesting comparisons and contrasts with the Mohonk, Minnewaska, and Otisville records. Birch (*Betula)* is better represented at this site, probably due to the local nature of the vegetation dominating the pollen record from the swamp. A decline in hemlock and birch along with ground pine (*Lycopodium)* signals the mid-Holocene drought, AMS-dated here at 4975 ^{14}C. The European impact is evident with the weedy ragweed (*Ambrosia),* plantain *(Plantago)* and grass (Graminae) rise in the top 30 cm**.** Relatively low hemlock percentages (10-15%) are more similar to Mohonk than to Minnewaska, while chestnut (*Castanea)* percentages were similar to Minnewaska and significantly lower (8%) than seen at Mohonk (up to 20%)

III. Lake Wallkill GIS Model

Methods

This paleo-topographic GIS model was constructed by first compiling a regional Digital Elevation Model (DEM) with a 23 m gird cell size. The model was then adjusted for isostatic rebound by assuming regional E-W isobase and total rebound slope of 0.70 m/km. Although this oversimplifies actual regional rebound, this slope is the same observed in the Champlain Valley and upper Hudson Valley (Rayburn et al., 2005; DeSimone et al., 2008), and similar to that illustrated in Stone, Stanford, and Witte (2002) and Stanford (in press).

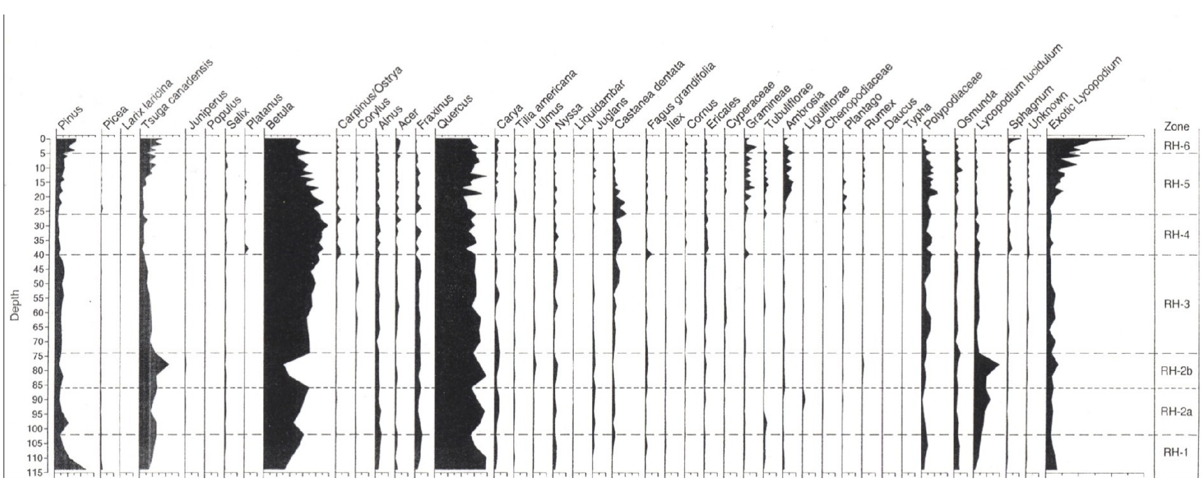

Figure 5. Pollen and spore stratigraphy from Rhododendron Swamp (Sage Markgraf & D. Peteet, analysts); remaining lower section is in progress.

Ice margins were digitized by modifying the Sussex, Pellets Island, Wallkill, and Rosendale ice margins published by Connally and Sirkin (1973) to fill the region, and estimating two intermediate ice margins at about New Paltz and Kingston. The Rondout and Wallkill Valleys were then flooded until they reached the Delaware River drainage divide. This was assumed then to be the highest lake level in each valley. The Hudson River basin was flooded to a level similar to that reported by Stanford (in press) to be the highest level of glacial Lake Albany.

The ice sheet was then made to recede from the oldest digitized margin (Sussex) to the youngest (Kingston) and as lower thresholds were uncovered lake levels in the valleys were adjusted to them. Drop in lake level could then be calculated.

Results

The descriptions below refer to Figure 6.

A) The model predicts the Wallkill/Delaware drainage divide threshold (yellow circle) at roughly the same location and elevation published by Connally and Sirkin (1973) at a modern elevation of 151 m (495 ft). This is the bedrock-floored spillway for the Augusta stage of glacial Lake Walkill (Stone, Stanford, and Witte, 2002; previously the "500 ft level" of Lake Wallkill of Connally and Sirkin, 1973). The ice margin shown in the Wallkill Valley is Connally and Sirkin's (1973) "Sussex" margin, and at this time Lake Wallkill drained to the North Atlantic via the Delaware River.

B) The next threshold published by previous studies is the one shown in Figure C. This model, however, identifies another threshold between A and C. The ice margin here is slightly modified from Connally and Sirkin's (1973) "Pellets Island" margin. A drainage divide is uncovered (yellow circle) that is 8 m above the threshold in A) given modern elevations, however when compensating for isostatic rebound, this threshold becomes 7 m below the threshold in A). If this is correct, then when the ice reached this position Lake Wallkill drained southward to the Atlantic Ocean via the Ramapo and Passaic Rivers, and the lake level dropped slightly (~7 meters). This is only a very minor change in lake level, and if this did happen it would probably be difficult to distinguish shoreline features between this level and the previous one. The Hudson Highlands separate the Wallkill from the Hudson drainage basin.

C) At Connally and Sirkin's (1973) "Wallkill" ice margin a significantly lower threshold across the Hudson Highlands is exposed (yellow circle). This threshold is at a modern elevation of 108 m (354 ft). The model shows this level to be 70 m below the threshold in A), which completely agrees with Stanford's (in press) estimate. This threshold would allow Lake Wallkill to discharge into Lake Albany via the Otter Kill and Moodna Creeks. Stanford (in press) calculates that this 70 m drop (not having recognized the potential lake level change in B) would send about 25 km^3 of meltwater into Lake Albany. He suggests that this flood overwhelmed the Lake Albany threshold at Hell Gate and caused the lake to overtop and breach the Narrows dam. This in turn would have lowered Lake Albany to a series of unstable levels (Lake Albany level changes are not depicted in this model). In the Wallkill Valley the most interesting observation from the model is that, given this ice margin position, Lake Wallkill appears to be nearly completely drained. Also, at this ice margin position the Rondout/Delaware drainage divide becomes exposed in the Rondout Valley, and a proglacial lake begins to form on the west side of the Shawangunk Mountains.

D) This figure shows a hypothetical ice margin at about New Paltz. A lower level of Lake Wallkill has become well developed east of the Shawangunk Mountains, and the lake in the Rondout Valley continues to extend northwards. This level of Lake Wallkill, referred to as the "400 ft level" by Connally and Sirkin (1973), is still controlled at the 108 m (354 ft) Otter Kill threshold.

E) The ice margin in this figure is shown at Connally and Sirkin's (1973) "Rosendale" margin, which they considered a re-advance position. They recognized a 320 ft. (98 m) level and a 220 ft. (67 m) level in the Wallkill Valley, but thought that perhaps they may relate to early stages of Lake Albany. At the Rosendale ice position, however, a threshold is exposed across the north end of the Marlboro Mountains (yellow circle) just east of New Paltz at the Swarte Kill/Black Creek drainage divide. This would direct discharge through the gap that Rt. 299 currently follows between New Paltz and Highland. Drainage would then have followed the Black Creek route

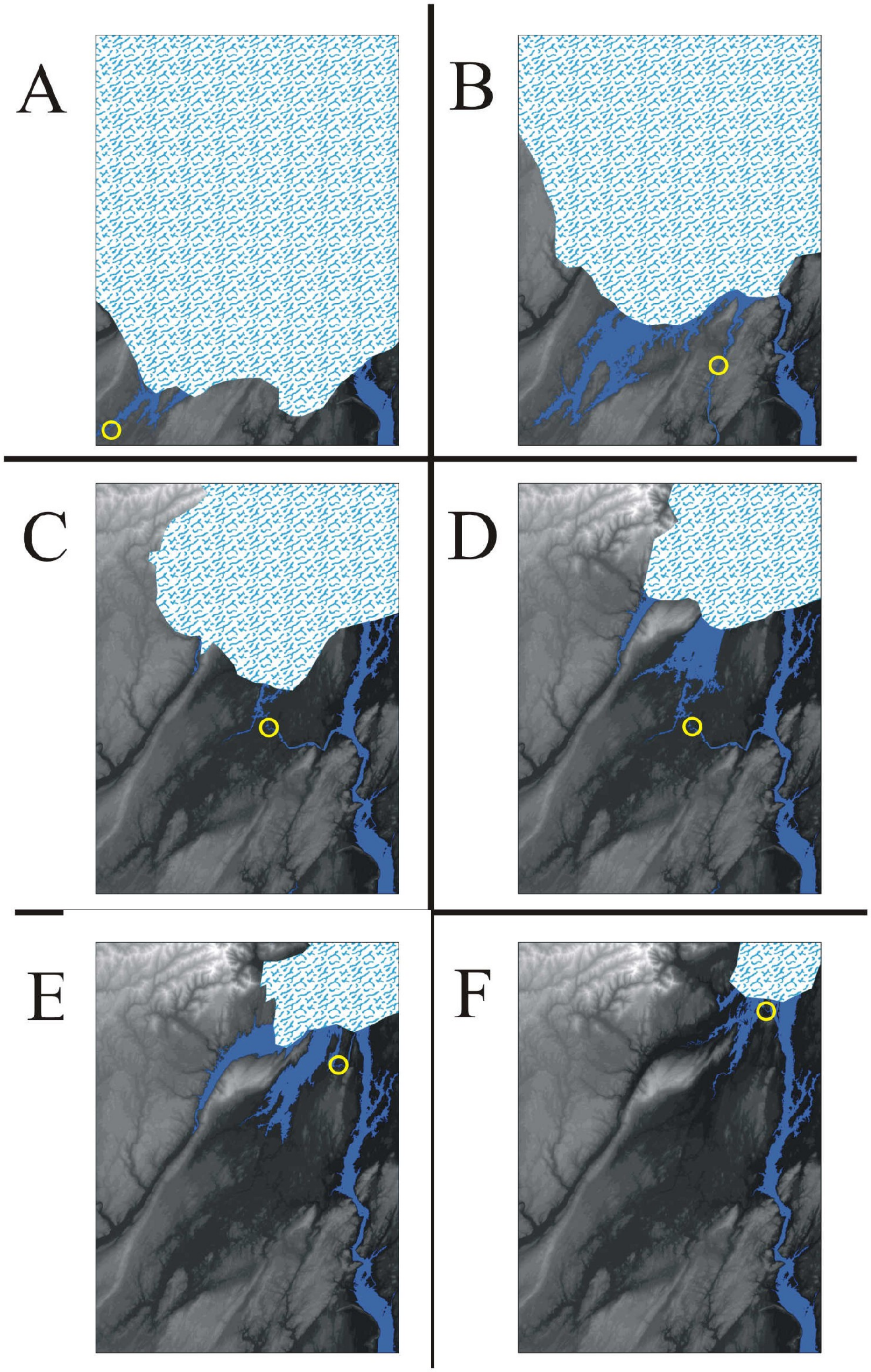

Figure 6. (see text for description)

north towards Esopus. Although currently 109 m (1 m higher than the Otter Kill threshold in D), this threshold would have been 21 m lower than the previous threshold given the estimated rebound. This would be a modest drop in the level of Lower Lake Wallkill. This ice position is pined against the north end of the Shawangunk Mountains, and this figure shows the glacial lake in the Rondout Valley at its maximum extent. When the ice retreats from the Shawangunks Lake Roundout will drop about 65 m to become confluent with Lower Lake Wallkill given the threshold depicted here. That should have caused a significant discharge through the Wallkill basin and into Lake Albany.

F) This figure shows a hypothetical ice margin position at about Kingston. At this point Lower Lake Wallkill extends into the Rondout Valley, and another threshold has become exposed (yellow circle). This threshold is at a modern elevation of 73 m (240 ft) and leads to the Hudson Valley through a gap called "The Hell" west of Ulster Park. This threshold, although not previously recognized is important for two reasons. First, the model shows that it was 46 m below the previous threshold, which would probably have caused a significant flood into Lake Albany. Secondly this elevation corresponds exactly with the deltaic deposit at Tillson and Rosendale. This is the best expressed lacustrine strandline in the lower Wallkill Valley, until discovery of this threshold, was difficult to account for. When the ice retreated to Kingston and exposed the entire Rondout drainage route, Lake Wallkill would have completely drained away into Lake Albany. According to Stanford's (in press) estimates for Lake Albany levels, the final stage of Lower Lake Wallkill was only about 15 m above Lake Albany.

IV. Wallkill Valley Regional Sites

Robinson et al. (2005) investigated pollen stratigraphies, including from mastodon and stag moose sites in the Wallkill Valley (Figure 7). as part of an ongoing project to reconstruct the climate, vegetation, fire history and large animal densities from the Pleistocene to present. Megafaunal populations collapsed throughout the region at the end of the Pleistocene, as ice sheets retreated and the earliest humans arrived. The study has included microscopic charcoal analysis to follow the fire history at the beginning of the Paleoindian period in the northeast. Distinctive fungal spores of the dung fungus *Sporormiella* were used as a proxy for megafaunal biomass. The results from several sites show reflect a rapid decline in spore values, closely followed by a stratigraphic charcoal rise, reflecting changes that unfolded at least 1000 years before the end Pleistocene climatic reversal of the Younger Dryas (YD). The YD is identified as pollen zone III from Binnewater Pond shown in Figs. 8, 9. Megafaunal fossil sites from the Black Dirt display a broadly similar microfossil stratigraphy, and pollen zones are readily correlated.

Although most direct bone dates of extinct megafauna suggest that these animals lasted until at least the beginning of the Younger Dryas. Robinson et al., 2005 suggest that a regional collapse of large herbivore populations was followed by landscape transformation by humans. Elevated stratigraphic charcoal could result from reduced herbivory or human caused fires, or both. The findings are consistent with the proposal that human activities rather than climate were the key drivers of the extinction event. And although these data in themselves give no indication as to actly how this may have happened, the fluted points of Dutchess Quarry Cave and other nearby sites are suggestive.

The rise in spruce in zone II (Figure 8) shows the shift toward the Bolling/Allerod warming; the overlying zone III is interpreted as the Younger Dryas cooling. When compared with the *Sporormiella* and the charcoal analysis in Figure 9 below, a drop in *Sporormiella* in zone II is seen, concurrent with the spruce increase and warming, while charcoal appears from the beginning of deposition and peaks in zone II.

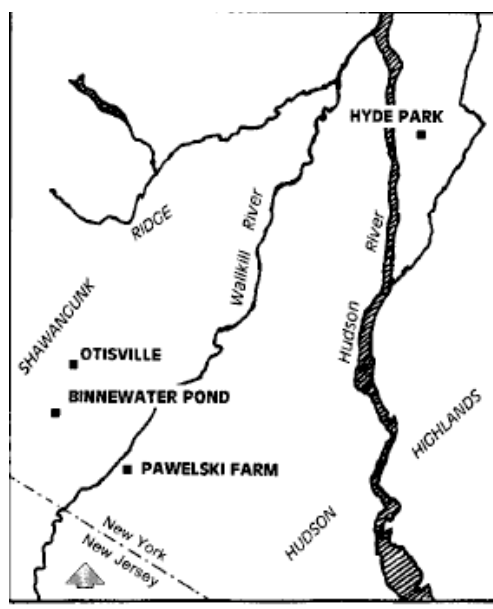

Figure 7. Sites investigated by Robinson et al (2005) in the Wallkill Valley.

Sporormiella spores are at least 3% throughout Zone I but decline below 1% in lower Zone II, whereas charcoal concentrations increase by 10 fold.

V. Hudson Marsh Paleoecology and Croton Point Varves and Till

Hudson marshes provide a unique perspective of the Hudson Valley climate because they are very high sedimentation archives, and record not only the pollen of the upland and marshes, but archive the inorganic component of a watershed as well as the charcoal in the watershed. Through the last decade, Peteet et al. (2006) have focused on the collection and analysis of Hudson River marsh cores for understanding the paleoenvironment of the estuary (Table 1, Peteet et al. 2006).

The pollen and charcoal record from Piermont Marsh (Figure 10), for example, documents the most detailed, well-dated Medieval Warm Interval between 850 and 1350 AD with very high charcoal and pine and hickory (Carya) expansion (Pederson et al., 2005), while the upper sediments record invasive species due to human impact.

Ongoing research on the cores from this site reveal sequences of apparent droughts and wet intervals which probably are correlative with the upland sequences from Mohonk, Black Rock Forest, and the Black Dirt region.

The upper meter of the Croton Marsh core sampled at 2cm intervals provides a glimpse of what the typical Hudson marsh looks like today (Figure 11), dominated by reed grass (*Phragmites*) which invaded the cattail (*Typha*) marsh, but which originally was comprised of sedges *(Scirpus, Cladium*) prior to European impact.

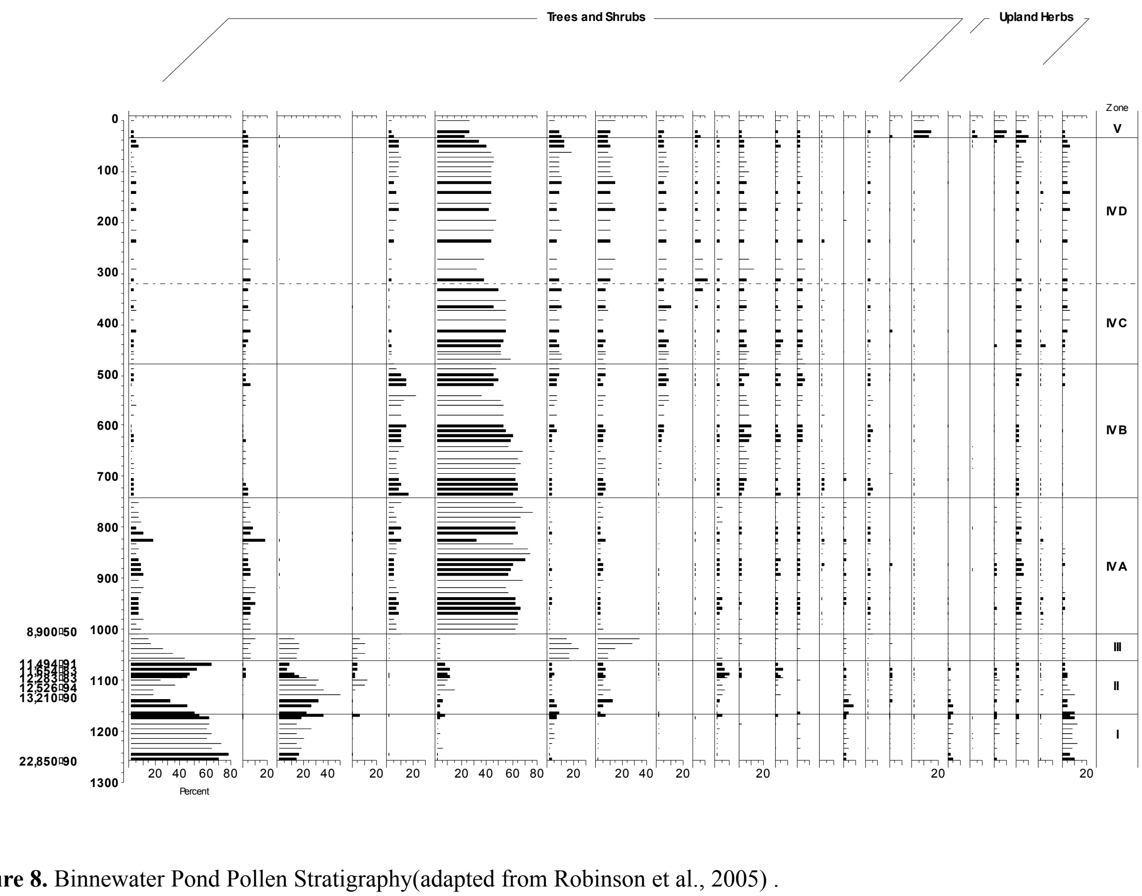

Figure 8. Binnewater Pond Pollen Stratigraphy(adapted from Robinson et al., 2005) .

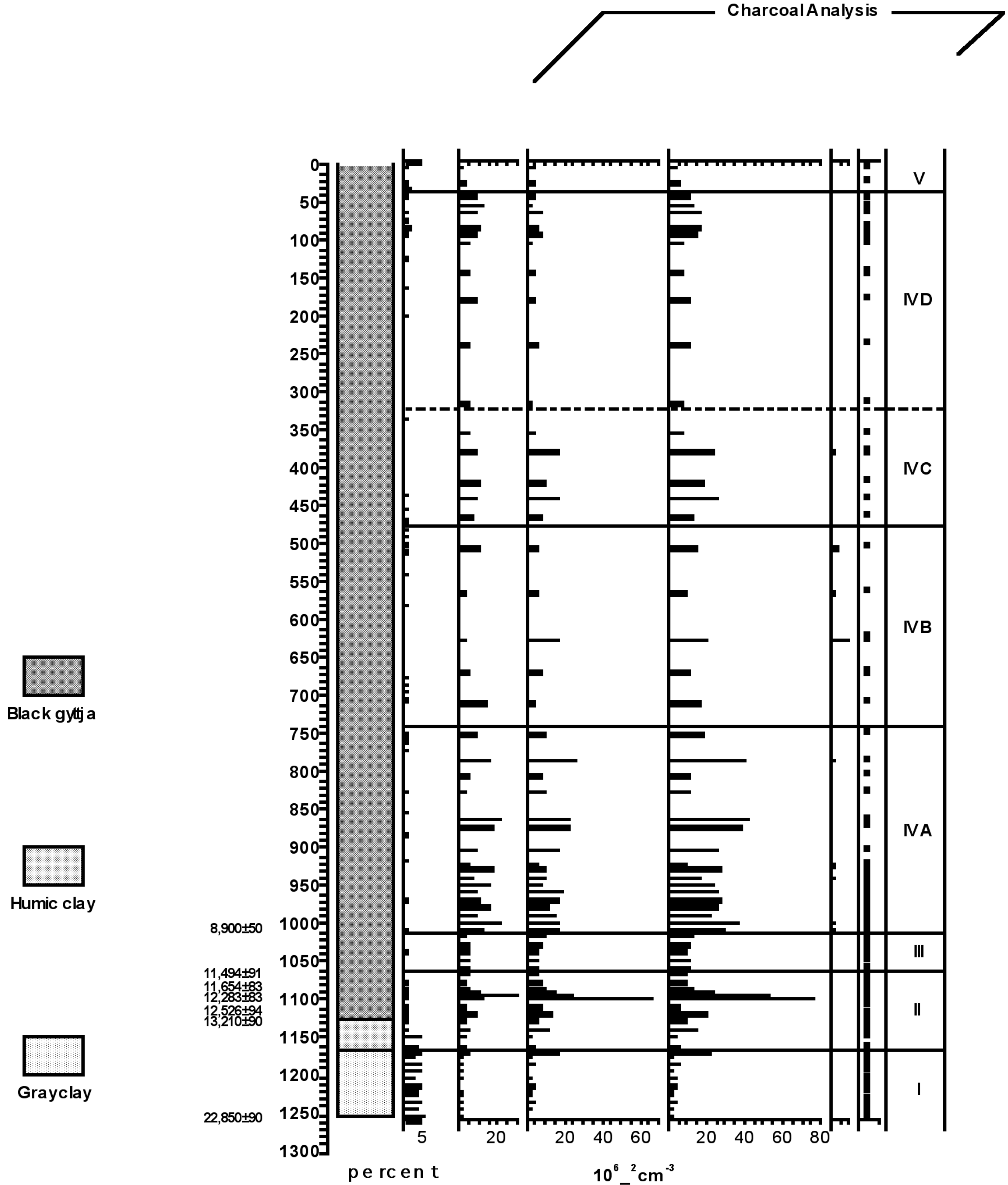

Figure 9. Binnewater Pond charcoal and Sporormiella (adapted from Robinson et al., 2005).

Table 1. Location, peat depth, and basal ^{14}C age of Hudson marshes.

Tidal Marsh	Latitude/ Longitude	Peat Depth	Basal ^{14}C Age
JoCo Jamaica Bay	40° 37'N 73° 47'W	2 m	>460 <2000
Yellow Bar Jamaica Bay	40° 37'N 73° 50'W	0.8 m	>450
Arthur Kill Staten Island	40° 36'N 74° 13'W	8.0 m	11,100
Hackensack New Jersey	40° 48'N 74° 04'W	3.7 m	2,610
Piermont N Piermont	41° 00'N 73° 55'W	13.7 m	5,700
Croton Marsh	41° 14'N 73° 50"W	10 m	4,630
Iona Marsh	41° 18'N 73° 58'W	10 m	5,500

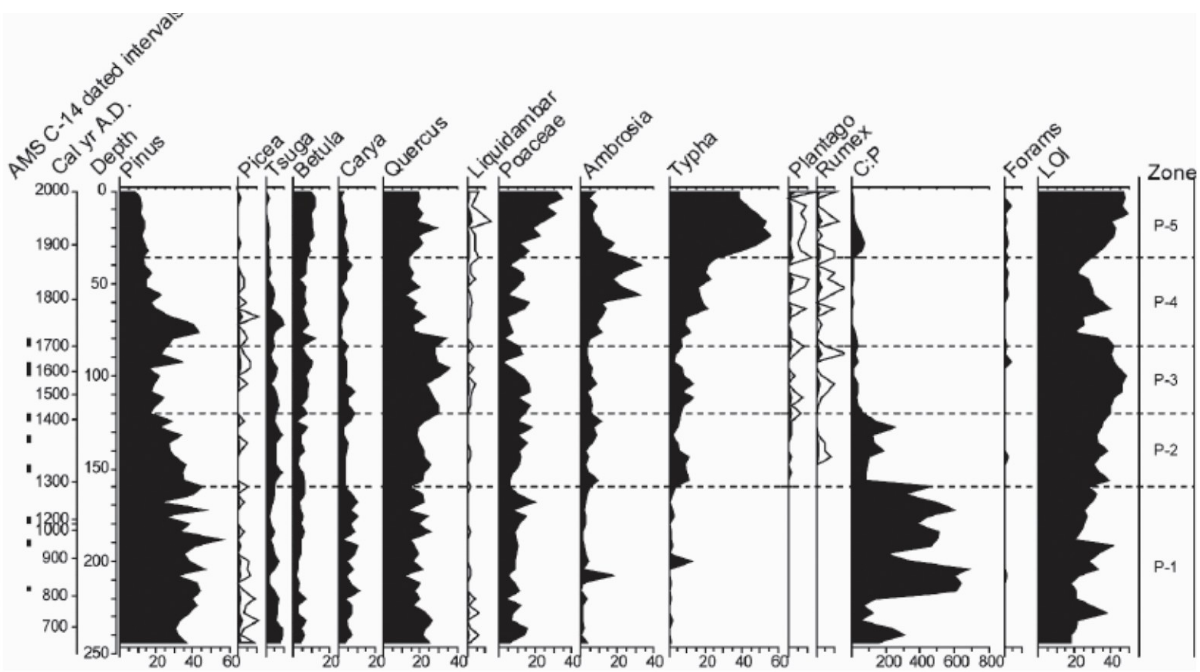

Figure 10. Pollen and charcoal/pollen stratigraphy from Piermont Marsh (Pederson et al., 2005).

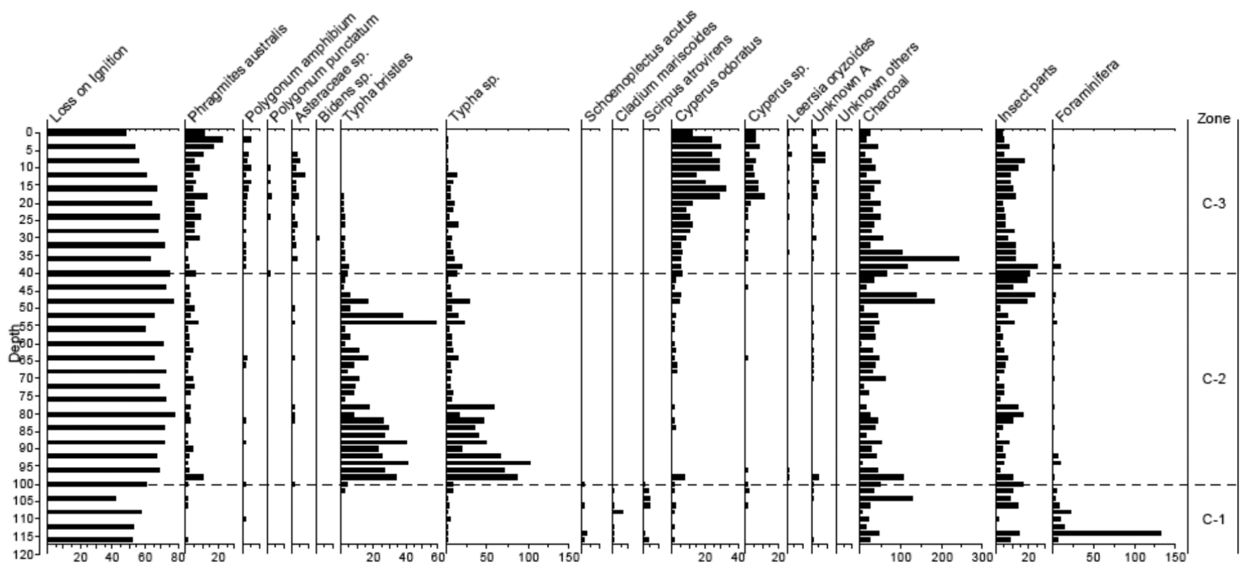

Figure 11. Croton Marsh loss-on-ignition and macrofossil stratigraphy in top 1.2 meter of the core (Caity Schubmehl and Dorothy Peteet, analysts).

At Croton, as in much of the Hudson estuary, marshes have been destroyed by landfills atop them. But the Croton archive has much to tell us about the regional droughts, and nearby Croton Point provides a unique river site to examine varve stratigraphy atop tills (see details in Stop).

Road Log

Miles Between Points	**Cumulative Mileage**	**Description**
0.0	0.0	Assemble at the parking lot adjacent to the Wooster Science Building on the SUNY New Paltz campus
0.02	0.02	Drive southeastward out of the parking lot and immediately turn left onto an unnamed campus rd.
0.10	0.12	Turn left (northwest) onto Plattekill Rd.
0.20	0.32	Bear left (west) onto Hasbrouck Ave.
0.20	0.52	Turn right (north) onto S. Chestnut St.
0.11	0.63	Turn left (west) onto Rt. 299/Main Street and cross the Walkill River.
0.32	0.95	Turn right (north) onto Springtown Rd.
0.47	1.42	Bear left (west) onto Mountain Rest Rd.
3.40	4.82	Turn left (southwest) at the entrance of Mohonk Mountain House
0.9	5.72	Pass through the check point and continue along the 1-way road.
0.87	6.59	Continue along the 2-way road.
0.06	6.65	Bear right at the Y in the road
0.07	6.72	Bear right again
0.13	6.85	Turn right onto Cedar Dr. and descend the hill
0.03	6.88	Turn right and park in front of Elms Cottage

Stop 1. Mohonk Lake. We begin our trip with a walk around the shores of Mohonk Lake, guided by Paul Huth, director of research for Mohonk Preserve. Starting in front of Mohonk Mountain House, a Victorian era hotel built in 1869 and operated continuously by several generations of the Smiley family, we will climb onto the quartz pebble conglomerate cliffs of the Silurian Shawangunk formation that surrounds the lake. Glacial striations and crescentic gouges are evident at several points along the trail, and Mohonk Lake itself is thought to have been formed by gla-

cial plucking of tectonically fractured bedrock. The sediment core described earlier in this guide was taken at the northern end of the lake near the Mountain House and spans most of the Holocene (see Figures 1-3). The first appearance of organic matter in the core dates to approximately 11.6 ^{14}C kyr b.p., in keeping with young AMS dates found at other sites in southern New York and New Jersey. In addition, the core appears to record a mid-Holocene drought episode that might have caused the decline of hemlocks previously attributed to a pathogen.

Continuing along the trail affords a view of Rhododendron Swamp from above. A paleoindian rock shelter adjacent to the swamp contains evidence of human habitation as early as 10 kyrs b.p. and possibly as early as 11.5 kyrs b.p. (Eisenberg, 1991). Ongoing paleoecological stratigraphy attempts to link the Swamp record to the archeological record..

End Stop 1. Retrace steps to depart Mohonk Mountain House Resort.
From Mohonk Lake to Dutchess Quarry Caves, Goshen, NY (as given by Google Maps).

1. Head south on Garden Rd 13 ft
2. Turn left to stay on Garden Rd 1.1 mi
3. Turn left at Terrace Rd 0.9 mi
4. Continue on Garden Rd 236 ft
5. Turn right at County Rte-6/Mountain Rest Rd 3.4 mi
6. Slight right at County Rte-7/Springtown Rd 0.5 mi
7. Turn left at County Rte-7/New Paltz Plaza/NY-299 W/State Route 299 W
   Continue to follow NY-299 W/State Route 299 W 1.6 mi
8. Take the ramp onto I-87 S Toll road 16.6 mi
9. Take exit 17 for NY-17K/I-84 toward Newburgh 0.5 mi
10. Merge onto Auto Park Pl 0.3 mi
11. Take the ramp onto NY-300/Rte-300/State Route 300 0.9 mi
12. Make a U-turn at Union Ave 69 ft
13. Take the ramp onto I-84 W 17.4 mi
14. Take exit 4E to merge onto NY-17 E toward New York 4.5 mi
15. Continue on US-6 E 0.3 mi
16. Take exit 124 for NY-207/NY-17A toward Florida/Goshen 0.3 mi
17. Turn left at NY-17A/Rte-17A/State Route 17A 2.1 mi
18. Turn right at Pulaski Hwy 0.5 mi
19. Turn left at Quarry Rd 0.3 mi
    Destination will be on the left. We park along Quarry Road and walk up to the caves on Mt Lookout.

Stop 2. Dutchess Quarry Caves: Paleoindian culture and Pleistocene Megafauna. Perhaps the most significant early human site in the northeast is at Dutchess Quarry, in a group of small caves formed in Paleozoic limestone on the northwest side of Mount Lookout in southern Orange County, NY. One complete and four partial Paleoindian fluted projectile points have been recovered from cave numbers 1 and 8 (Funk et al., 1969; Funk et al., 1970; Kopper et al., 1980; Funk and Steadman 1994) Bones of caribou, (*Rangifer tarandus*), extinct flat-headed peccary (*Platygonus compressus*) and the extinct giant beaver (*Castoriodes ohioensis*) have been among the 71 species of vertebrates discovered, although there is no clear association between any of the Pleistocene fauna and the cultural material (Steadman, Stafford and Funk 1997).

At an elevation of 177m Mount Lookout offers a view from 80m above the Black Dirt agricultural region, itself lying over the largest accumulation of terrestrial peat in eastern United States after the Florida Everglades. A succession of proglacial lakes occupying the Wallkill River Valley left a large, poorly drained area that was to become an immense peat deposit continuing to build throughout the Holocene. By the early 20th Century, these mucklands were being artificially drained for agriculture. Occasionally, maintenance of drainage ditches exposed the remains of the extinct Pleistocene megafauna. In this way, numerous mastodons (*Mammut americanum)* and at least three stag moose skeletons (*Cervalces scotti*) have been discovered in and around this vast wetland. The two most recent of the stag moose have been AMS dated to 12,180+/-60 and 11,040+/- 110 ^{14}C yrs before present. The latter individual is the latest known occurrence of this species in North America.

Depart Mt. Lookout.
Start at: Quarry Rd Goshen, NY 10924

1. Head northeast on Quarry Rd toward Florida Rd/Florida Green Dr/NY-17A/Rte-17A/State Route 17A - 0.1 mi
2. Turn right at Florida Rd/Florida Green Dr/NY-17A/Rte-17A/State Route 17A - 0.6 mi
3. Turn left at Durland Rd - 0.7 mi
4. Turn left at NY-94/Rte-94/State Route 94 Continue to follow NY-94/Rte-94 - 2.7 mi
5. Turn left at West Ave - 0.5 mi
6. Turn right at Brookside Ave - 0.2 mi
7. Turn left at Academy Ave - 0.2 mi
8. Turn left at Main St - 0.3 mi
9. Continue on High St/NY-94 Continue to follow NY-94 - 14.4 mi
10. Turn right at Forge Hill Rd - 1.4 mi
11. Continue on Sloop Hill Rd - 486 ft
    Arrive at: Sloop Hill Rd New Windsor, NY 12553

Stop 3. Newburgh Terrace.

The only available exposure of glaciolacustrine deposits on the west side of the Hudson River is in this pit at the mouth of Moodna Creek on the south side of Newburg. The pit is in the south side of the excavated terrace that has a surface altitude of over 49 m (160 ft). A small inset plain at the top of the exposure had a surface altitude of just above 33 m (100 ft). The pit exposes: 1) cobble gravel at the surface, 2) glaciolacustrine beds that extend to the bottom of the cut. The gravel, 1-2 m thick, underlies the inset terrace surfacecut into the southern part of the original higher glacial terrace landform. The gravel rests on a sharp, horizontal disconformity with the underlying sand. The surface of the gravel plain is correlated with nonspecific levels of glacial Lake Albany, projected from deltas surfaces and topset-foreset contacts from deposits east and north of this site. The gravel in this exposure is a thin, postglacial fluvial terrace deposit, probably graded to lowering lake levels in the valley.

Figure 12. Fluvial cobble gravel disconformably overlying glaciodeltaic sand deposits in the 49 m (160 ft) terrace at the mouth of Moodna Creek south of Newburgh, New York.

The glaciolacustrine sand deposit consists of alternating, laterally continuous beds of fine to coarse sand, pebbly sand, and very fine sand and silt. Basal bedding contacts are sharp; bedding forms are chiefly flat thin beds and laminations, with few ripples and hummucky forms. Color of beds is related to their composition and, therefore, their particle size: coarser beds are lighter colored and contain quartz, some feldspar, minor carbonates, and scattered pebbles of carbonate and sandstone. Darker beds are finer grained and contain platey rock frag-

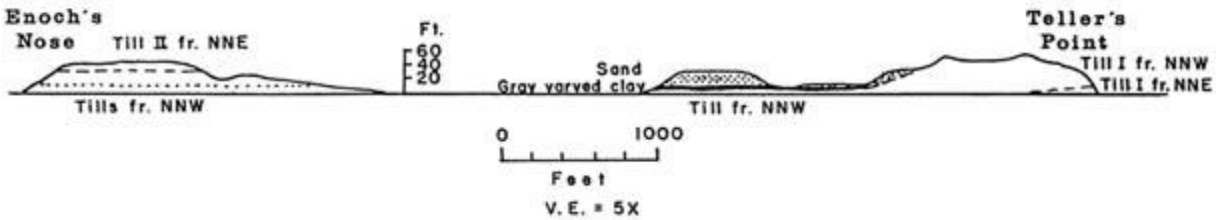

Figure 13.

ments of shale and some carbonate. The lake beds have a gentle southerly slope of <1o reflecting their subaqueous origin as bottomset beds of an ice-marginal delta deposited in glacial Lake Albany.

The excavation exposed on this trip affords us an opportunity to determine the local vertical successions of delta bottomset underflow deposits, their cross-cutting relationships, and paleocurrent flow directions.

1. Drive north on Sloop Hill Rd. toward Shore Rd. - 0.2 mi
2. Turn left onto US-9W South. - 13.4 mi
3. Enter next roundabout and take 3rd exit onto US-202 North/US-6 East. - 0.2 mi
4. US-202 North/US-6 East becomes US-6 East/US-202 East (Portions toll). - 4.1 mi
5. Enter next roundabout and take 1st exit onto US-202 East/US-6 East/US-9 South/Lower South St. - 0.2 mi
6. Turn right onto US-202/US-6/US-9. Continue to follow US-9 South. - 8.2 mi
7. Take the Croton Point Ave ramp. - 0.2 mi
8. Turn right onto Croton Point Ave. - 0.4 mi
9. Arrive Croton Point Park

Stop 4. Croton Marsh. Archeological evidence indicates that the Croton region was populated by the Kitchawanc tribe as early as 5000 BC. The marsh was called Senasqua, Croton itself is believed to be named for the local Indian Chief, meaning “wild wind”. A 1718 census of the area counted 91 inhabitants in the Manor estate of Cortland, including Dutch settlers and English Quakers (http://www.crotononhudson-ny.gov). An overview of the Croton Marsh remaining from the landfill road to the south of the entrance to Croton Park. Today, one can only see the invasive Phragmites communis covering the site, but prior to European impact it was comprised of a diverse sedge mixture. Peteet et al. extracted a 10m marsh core and pollen/macrofossil work on the core is in progress.

Park at parking lot closest to Nature Center, and walk south to river exposure.

Stop 5. Croton Moraine and Varves. A summary of Croton Point Pleistocene glacial history is provided by Sanders and Mergurian (l994). It is as follows:

1) Several tills starting with gray-tan, then red-brown, then, after red outwash was deposited, another red-brown till, followed by the yellow-brown till. The red-brown tills contain erratics from the west side of the

Figure 13. Varves atop till at Croton Point. Photo by D. Peteet.

Hudson River whereas the youngest and oldest tills contain only rocks found on the east side of the Hudson River.

2) After the youngest of the tills had been deposited and the glacier responsible for it had melted away, the region was flooded. All the drainage from the Great Lakes flowed eastward through the Mohawk Valley and down the Hudson. Proglacial Lake Albany was backed up behind the natural dam of till at the Narrows. Deltaic sediments from the ancestral Croton River and possibly drainages to the north were deposited along the east shore of this lake. The water plane presumably stood at about elevation +70 feet (level of the flat terrace underlain by topset beds of the delta that coincide with the uppermost water level). To the west, the depth of water where the clay was deposited away from influence of the delta was 70 feet. The coarse browner clays probably represent the dark suspended load of the river(s). The light clays are winter deposits when river(s) experienced low- flow conditions and/or were shut down altogether because their waters froze solid.

Figure 15. Varves at Croton Point. Photo by D. Peteet.

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