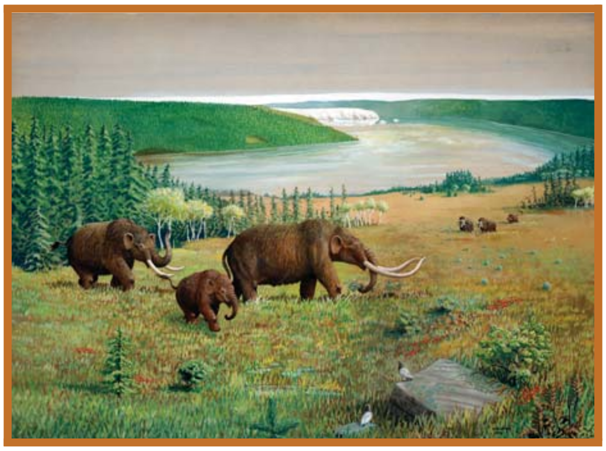

Mastodon Paleobiology, Taphonomy, and Paleoenvironment in the Late Pleistocene of New York State: Studies on the Hyde Park, Chemung, and North Java Sites

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EXCAVATING AND INTERPRETING FLOODED MEGAFAUNAL SITES

David A. Burney
Department of Biological Sciences, Fordham University, Bronx, New York 10458, U. S. A. Current address: National Tropical Botanical Garden, 3530 Papalina Road, Kalaheo, Hawaii 96741, U. S. A., email dburney@ntbg.org

and Guy Robinson
Department of Natural Sciences, Fordham College at Lincoln Center, 113 West 60th Street, New York, New York 10023, U. S. A.

ABSTRACT
A method is described that allows the controlled excavation of mastodon bones found in sites below the water table. Under optimal conditions of neutral sediment pH, low-energy sedimentation, and reducing chemistry, these sites can yield, in relatively intact sequence, a record of pollen, spores, diatoms, charcoal particles, plant macrofossils, vertebrates, and invertebrates. These forms of evidence in combination can provide a detailed picture of changes at the landscape level before, during, and after megafaunal collapse. Integrated analysis of subphreatic sites has played a role in evaluating at least 13 hypotheses that have been proposed to explain the megafaunal extinction event in end-Pleistocene North America, and a pattern of similar extinctions throughout the peripheral continents and oceanic islands of the world following human arrival.

INTRODUCTION
Digging mastodon skeletons out of saturated mud is nothing new. Two centuries ago, the first mastodon ever excavated was from a flooded site near Newburgh, New York. A contemporary painting (Text-Fig. 1) shows Charles Willson Peale's elaborate set-up for digging the bones that so impressed Thomas Jefferson (Semonin, 2000). Diligent teamwork by experienced diggers who are not afraid of wet feet was important to this enterprise then, as now. Devices for pumping water efficiently were and are as essential to this type of scientific enterprise as they were in the early coal mines that fueled the Industrial Revolution.

In recent decades there has been a resurgence of interest in excavating flooded sites containing extinct late Quaternary vertebrate remains for reasons that entail forms of analysis not anticipated by early investigators. Refined techniques for controlling water levels in flooded sites improve stratigraphic controls. The result, when teamed up with palynological, micropaleontological, and biogeochemical techniques, is a major advance in the reconstruction of past biotic landscapes. The level of breadth and detail has greatly enhanced paleoecology's relevance for understanding general environmental principles and recovering landscape-level specifics of likely use in planning ecological restorations (Burney *et al.*, 2001, 2002). If stratigraphic recovery and interpretation have sufficient chronological resolution, these reconstructions can be decidedly less like a "snapshot" of the past, and more like a "movie."

The enticing possibility exists that flooded late Quaternary sites might contain a century-by-century account of many inter-related ecological events and coeval organisms from the analysis of a combination of lithology, pollen, spores, charcoal, plant macrofossils, and invertebrate and small vertebrate remains – not to mention the bones, coprolites, and perhaps other evidence from extinct megafauna – along with direct and indirect evidence for climate change, initial human contact, and subsequent anthropogenic and natural changes. Such sites are likely to be our best chance to uncover potential causes for the dramatic biotic changes at the end of the Pleistocene in North America and at various times before and since throughout the rest of the world.

METHODS
To understand the global pattern of late prehistoric extinctions, scientists have made good use of the fact that islands might be simpler systems in which the extinction events of interest occurred much more recently than on the continents. Early attempts to do integrated site analysis on fortuitously diverse and well-preserved sites of the right age and resolution for studying island extinctions were carried out in Madagascar (MacPhee *et al.*, 1985), Hawaii (James *et al.*, 1987), and the South Pacific (reviewed by Steadman, 1995). This work has demonstrated the absolute importance of careful stratigraphic

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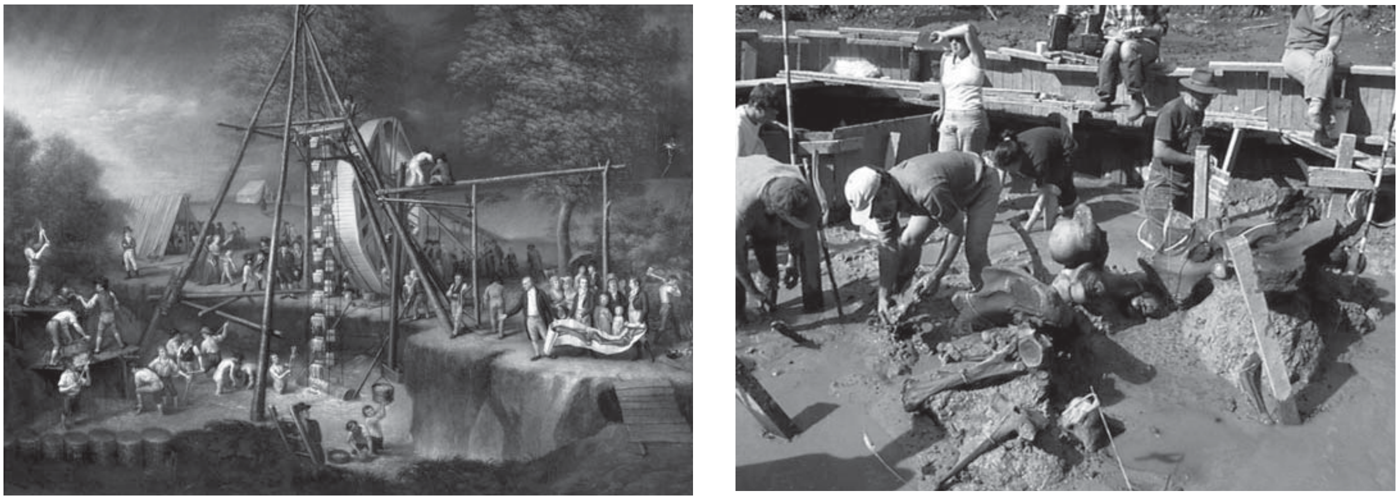


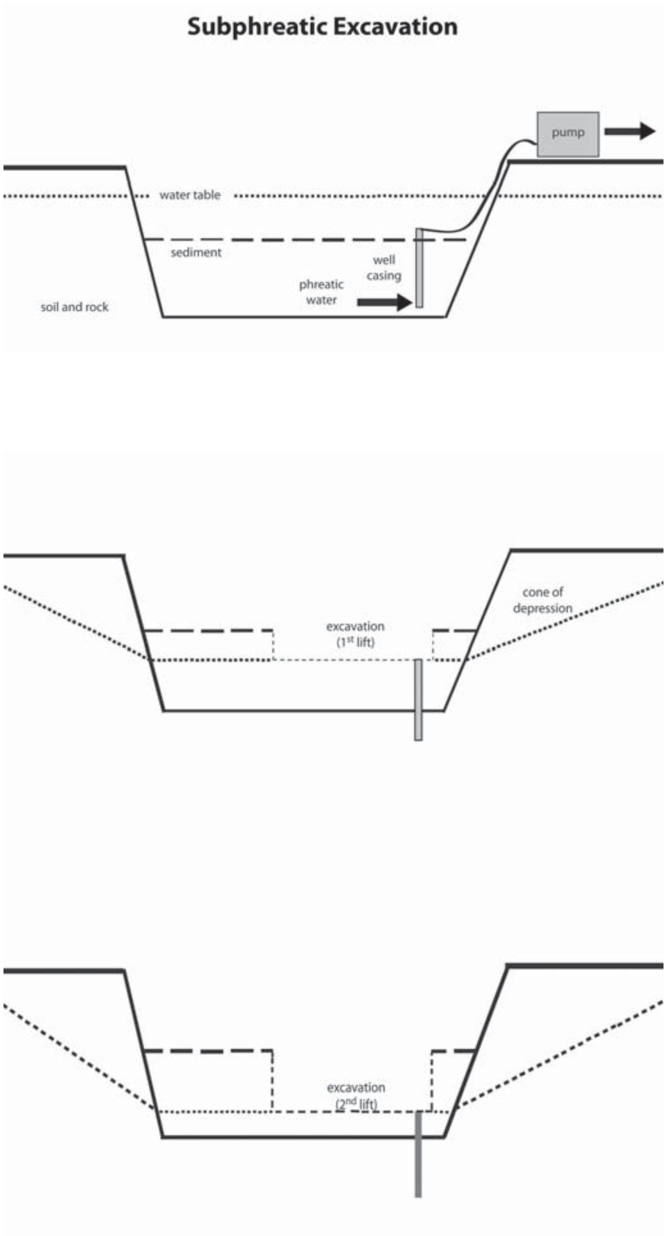
Text-fig. 1. Two centuries of subphreatic mastodon excavation. Painting by Charles Willson Peale (1806) (*left*) depicts the first mastodon excavation, which fascinated Thomas Jefferson, in Newburgh, Orange County, New York. Note the elaborate water pump driven by a human treadmill (courtesy of the Maryland Historical Society). Across the Hudson River at Hyde Park, New York (*right*), investigators two centuries later use smaller and more efficient pumps but still get muddy. In foreground (*at left*), Dan Fisher lifts out mastodon bones while describing their position for taphonomic studies. David Burney (*at right*) bags sediment samples and describes the stratigraphy while removing the sediment in thin layers with small hand tools (photo by Robin Andersen).

control in places notoriously difficult in this regard, from mucky swamp sediments to the bone-dry dust of lava-tube caves. Absolute dating by radiocarbon has received a huge boost in its efficacy for studying these extinction events through the use of Accelerator Mass Spectrometry and the development of sophisticated protocols for pretreating various types of plant and animal remains to remove their respective likely sources of exogenous carbon. By generating a detailed chronology based on dating and comparing a wide variety of organic materials, the limitations on dating of one type of material can, in theory at least, be offset by combination with the advantages of others.

With regard to ^{14}C chronologies, however, the major extinction events in Australia (Flannery, 1994) and the Americas (Martin, 1984, 1990) have posed notorious difficulties, the former because the event apparently is slightly too old for precise ^{14}C dating, and the latter because megafaunal collapse in the Americas comes within an interval of time around twelve millennia ago when calibration leaves most otherwise interesting dates essentially indistinguishable at the 95% confidence interval (2σ). It is in this type of challenging situation that recent studies have turned increasingly to microstratigaphic techniques familiar to palynologists to refine the "before and after" causal sequences of interest to those testing hypotheses concerning putative factors in the extinctions (see Robinson & Burney, 2008).

A recent key innovation in digging well below the water table with the type of stratigraphic control demanded by site-integration techniques was literally taken to new depths in a study in a flooded sinkhole on Kaua'i (Burney *et al.*, 200l), reaching 5 m below the water table in a 10 × 20 m pit while maintaining < 10 cm provenance on the vertical axis and 1 m on the horizontal. The essence of this technique is to hybridize the standard techniques for controlled excavation with simple well-drilling technology (Text-Fig. 2). As the excavation pit reaches the water table or floods by surface or vadose water, a cased hole is drilled into the floor of the excavation by means of a hand-operated bucket auger with PVC (polyvinyl chloride) casing. The suction head of a water pump is inserted into the cased hole, and, by pumping just enough to lower the water level into the casing *ca.* 10 cm below the lip, but no more, the water level can be maintained in all but the most porous inorganic sediments with exactitude. This approach is in marked contrast to the natural tendency of those inexperienced in the use of water pumps for this purpose. "Over-pumping" results in surging water levels, as the pump depletes its reservoir, dries out, and temporarily loses its prime until the water level once again rises.

By careful measurement and fine adjustment of the pump or pumps, it is possible to use the water itself as a superb leveling device, setting the level to define the bottom of the current interval of sediment being excavated (*e. g.*, 10 cm per lift). When the layer has been removed, the pump head is advanced 10 cm deeper, or to whatever desired level relative to datum, and excavation again proceeds to remove all material down to the new water level formed by the resulting cone of depression that is temporarily formed in the local water table.



Text-fig. 2. With careful pumping, sediment can be removed from flooded sites with good stratigraphic control. (*Top*) The pump draws phreatic-zone water from a cased hole. (*Center*) As a temporary cone of depression forms in the water table, the level is stabilized at the bottom of the lift, with a thin layer of sediment being dug away. The water provides a consistent leveling device over the entire area. (*Bottom*) To dig the next lift, the suction head is lowered and/or pumping speed is increased slightly to lower the water level the desired amount, again using the water itself to define the bottom of the lift.

As the articles in this volume attest, this technique was employed with good success at the Hyde Park Site, Dutchess County, New York. The only drawback here, as in other proboscidean sites, is that removing large bones can somewhat disrupt the stratigraphy. Here, though, as in other integrated sites of this type, the finer-scaled stratigraphic samples for pollen, spores, diatoms, microscopic charcoal, seeds, and other small fossils, can be extracted from an intact wall of the pit, while the water is held at a low level. This is also the ideal time to describe lithology, take photographs, and sketch the sediment layers.

APPLICATIONS

The accelerated application of integrated site analysis by those studying late Quaternary extinctions around the world has lead to increasing interest in expanding the scale of paleoecological investigation to the entire landscape. A key requirement for this type of analysis was well-met at Hyde Park: that the stratigraphic array contain well-preserved remnants of both the acidophilous plant remains (pollen, spores, and plant macrofossils generally are best preserved in sites with sediment pH < 7.5), and the alkalophilous remains of animals (bones and shells are generally found in sites with an ambient pH > 6.5). We find that approximately neutral sediments are most likely to yield the diverse results required for the maximal recovery of the widest array of ecological information. The broad spectrum of results presented in this volume show clearly that the Northeast has good potential for more refined landscape paleoecology. For additional examples in the region, see Robinson (2003).

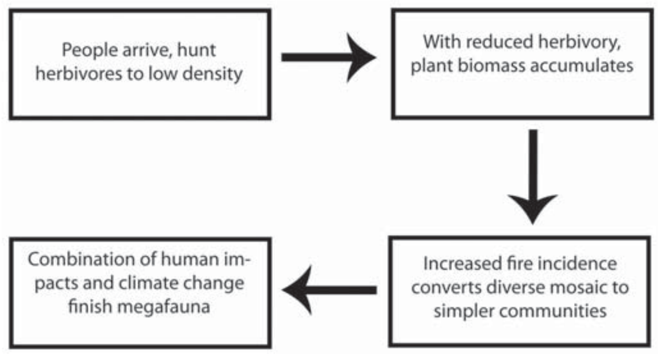
Now that we have begun to develop this new potential for peering into past millennia, how shall we use it? As has been demonstrated in studies of similar sites elsewhere, one fertile application is to "dissect" an extinction event by using the refined picture of past changes on the landscape to tease apart the empirical evidence for the sequence of key events and compare these details to the predictions of each hypothesis proposed for the cause of the extinctions. This is made more explicit by creating a conceptual matrix for the predictions of each hypothesis in terms of the rate, pattern, and inferred processes associated with these alterations of the biotic landscape (Burney, 1999).

We have identified 13 hypotheses (Table 1) that have been proposed to explain the extinctions here and elsewhere that are seemingly explicit enough in predicting rate, pattern, and process to generate useful tests, following the "multiple working hypotheses" approach first proposed by T. C. Chamberlain (1890). These hypotheses can usefully be classified into three groups: those that invoke climate change, overkill, or something else. The latter group contains both single-cause explanations, such as hypervirulent disease (MacPhee & Marx, 1997), and multicausal explanations.

As work continues in testing these hypotheses with new powerful empirical tools (see articles in this volume), a related

Table 1. Proposed hypotheses for late prehistoric extinctions.

	Type	Source	Rate	Pattern	Process	Comments
H1	Climate change	Graham & Lundelius, 1984; Guthrie 1984	Slow?	A mosaic vegetation pattern becomes zonal; follows climate gradient	Climate changes lead to less hospitable environments for certain large species, which fail to adapt	
H2	Environmental insularity	King & Saunders, 1984	Slow?	Extinction follows as boreal forest recedes northward	Rapid expansion of deciduous forest suddenly reduces available habitat	Applies only to the extinction of the American mastodon
H3	Rapid climate cooling: the Younger Dryas	Berger, 1991	Rapid	Follows climate gradient at *ca.* 11,000 ^{14}C yr BP (Younger Dryas)	As above, but change is more drastic and develops rapidly	
H4	Blitzkrieg, or rapid overkill	Martin, 1984	Rapid	Wave through region	Naïve fauna rapidly hunted to extinction	
H5	Protracted overkill	Whittington & Dyke, 1984; Fisher, 1997	Slow	Slow wave, or mosaic pattern of megafaunal collapse	Initially naïve fauna; overexploitation eventually causes collapse	
H6	Predator pit	Janzen, 1983	Rapid	Wave through region	Humans and native predators each contribute to collapse	
H7	Second-order predation	Whitney-Smith, 2001	Moderately rapid	Pulsed	Interactions between humans, carnivores, herbivores, and vegetation	
H8	Three-stage overkill	Alroy, 2001	Rapid	Pulsed	Overkill sufficient to explain pattern	
H9	Clovis age drought	Haynes, 1991	Rapid	Severe but temporary vegetation change following human arrival, at *ca.* 11,000 ^{14}C yr BP	Arid conditions spread, rapidly amplifying predation by humans	
H10	Hypervirulent disease	MacPhee & Marx, 1997	Very rapid	Panzootic disease pattern	Infectious disease with trans-generic virulence	
H11	Keystone megaherbivores	Owen-Smith, 1987; Zimov *et al.*, 1995; Schüle, 1990	Not specified	Landscape transformation and fire follow megafaunal collapse	Megaherbivores, which maintain open forest, are removed by humans or disease	Fire regime changes as forests close and fuel loads rise (Schüle, 1990)
H12	Great fire	Humbert, 1927; Miller *et al.*, 1999	Rapid	Simultaneous throughout large regions	Landscape transformation by anthropogenic fire; extirpation follows loss of forage	Proposed for Madagascar; applicable to North America
H13	Synergy	Burney, 1993a, b, 1999; Diamond, 1984	Slow	Mosaic	Human and natural causes interact	



Text-fig. 3. A box model to show the chronological sequence envisioned by the Synergy Hypothesis. This pattern is consistent with the documented trends, starting with a drastic decline in the coprophilous fungus spore, *Sporormiella,* a proxy for megafauna, followed by a very large increase in sedimentary charcoal. Dates on the latest known occurrences of megafauna come somewhat later. Although proof of a direct human role is still scarce, the described sequence of events is out of phase with major climate changes in the region.

project has gained traction from comparing new data from the Northeast with recent results from around the globe. Several investigators have proposed conceptual and quantitative models that attempt to integrate many types of evidence. The quantitative models of Alroy (2001) and Whitney-Smith (2001), although proposed to support a single primary cause, emphasize the great future potential of computer modeling for capturing more of the apparent complexity of these events. Hypotheses such as Synergy (Burney, 1999) explicitly invoke the nonlinear biotic responses that can be expected if multiple causes interact. The primary limitation of this idea until recently has been that, although much information collected from integrated sites such as subphreatic excavations is consistent with the hypothesis, few specific mechanisms of interaction have been recognized in the fossil record.

This limitation has recently changed. Sites in the northeast (Robinson, 2003; Robinson & Burney, 2008) and in Madagascar (Burney *et al.*, 2003) demonstrate that the decline of megafaunal populations, as inferred from drastic decrease of coprophilous fungus spores, consistently leads a large increase in microscopic charcoal particles. Further, these disparate data sets show that these changes are not correlated with the largest climatic changes registered in these sites (see Kerr, 2003). Furthermore, work in these two areas shows that latest occurrence of megafauna at the same sites postdate the initial decline and fire increase by 1-2 millennia, suggesting a more drawn-out extinction event than that predicted by simpler models.

These new bits of information have given impetus to the conceptual model for late Quaternary ecosystem collapse that invokes the synergistic interactions of these inferred events (Text-Fig. 3). Recent data, including the Hyde Park evidence (Robinson & Burney, 2008), suggest that megafaunal populations declined rapidly at approximately the time of human arrival, followed within a few centuries by a drastic increase in fire in the environment, probably owing to the increase of the standing crop of vegetation and plant litter near the ground in the absence of abundant megaherbivores. The resulting environmental changes precede the largest known abrupt climate change in this time period (Younger Dryas) by many centuries. Somewhat later still, perhaps in Younger Dryas times, the last of the megafauna disappear. Empirical evidence from careful site integration therefore supports the notion that humans or some unknown factor set in motion a phase transition in the ecological dynamics of the landscape that culminated in the loss of three-quarters of the continent's large animal genera, and paralleled similar events that herald the arrival of humans in many other parts of the world at various times throughout the late Quaternary.

Regardless of which of these hypotheses, or some other, ultimately gains acceptance as an explanation for these remarkable events, it is clear that the rich new details recently gleaned from flooded mastodon sites in New York State will make an important contribution to our understanding of the most remarkable biotic collapse known in the Quaternary and perhaps in the entire Neogene.

CONCLUSIONS

Although muddy mastodons have played an important role in the two-century history of late Quaternary paleontology in the northeastern U. S., refinements in techniques for pumping, stratigraphy, and microfossil analysis now make flooded sites more interesting than ever. Sites with approximately neutral pH, low-energy sedimentation regimes, and reducing conditions can provide not just megafauna, but also microfaunal bones and shells, pollen and spores, plant macrofossils, charcoal particles, diatoms, and a host of other sources of information essential to a more complete reconstruction of the past. By careful attention to chronological details, it has become increasingly possible to evaluate cause and effect in relation to the megafaunal extinctions. With careful study, these muddy holes could be the closest thing to a real time machine that any of us will ever experience.

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