Dendrochronological Analysis of Brandywine Mansion/Rebecca Lukens House, Coatesville, Chester County, Pennsylvania

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Introduction

This is the final report on the dendrochronological analysis of the structure known variously as the Brandywine Mansion and as the Rebecca Lukens House, at 102 South First Avenue, Coatesville, Chester County, PA 19320 (39º58'50"N, 75º49'17"W). The site is owned by the Graystone Society and is located on the grounds of the National Iron & Steel Museum in Coatesville, Pennsylvania, on the former property of the Lukens Steel Company, 50 South First Avenue, Coatesville, PA 19320. In an effort to describe the construction history of this building, Dale Frens AIA, of Frens & Frens Restoration Architects, 120 South Church St., West Chester PA 19382, acting on behalf of the Museum, requested that dendrochronologists William Callahan and Dr. Edward Cook perform a tree-ring analysis of selected structural timbers.

Together with Mr Frens, Callahan visited the site on 6 and 11 December 2013 and collected core samples for the dendrochronological analysis of the timbers. Of the 12 field samples taken, 9 were of sufficient quality for submission for laboratory analysis. All were of oak (Quercus sp.). Every effort was made on site to locate bark or waney edges on the sampled timbers in order to ascertain the absolute cutting date, or dates, of the trees used in the construction.

Dendrochronological Analysis

Dendrochronology is the science of analyzing and dating annual growth rings in trees. Its first significant application was in the dating of ancient Indian pueblos of the southwestern United States (Douglass 1921, 1929). Andrew E. Douglass is considered the "father" of dendrochronology, and his numerous early publications concentrated on the application of tree-ring data to archaeological dating. Douglass established the connection between annual ring width variability and annual climate variability which allows for the precise dating of wood material (Douglass 1909, 1920, 1928; Stokes and Smiley 1968; Fritts 1976; Cook and Kariukstis 1990). The dendrochronological methods first developed by Douglass have evolved and been employed throughout North America, Europe, and much of the temperate forest zones of the globe (Edwards 1982; Holmes 1983; Stahle and Wolfman 1985; Cook and Callahan 1992, Krusic and Cook 2001). In Europe, where the dendrochronological dating of buildings and artifacts has long been a routine professional support activity, the success of tree-ring dating in historical contexts is noteworthy (Baillie 1982; Eckstein 1978; Bartholin 1979; Eckstein 1984).

The wood samples collected from the Brandywine Mansion/Rebecca Lukens House were processed in the Tree-Ring Laboratory by Dr. Edward Cook following well-established dendrochronological methods. The core samples were carefully glued onto grooved mounts and all were sanded to a high polish to reveal the annual tree rings clearly. The rings widths were measured under a microscope to a precision of ±0.001 mm. The cross-dating of the obtained measurements utilized the COFECHA computer program (Holmes 1983), which employs a sliding correlation to identify probable cross-dates between tree-ring series. In all cases, the robust non-parametric Spearman rank correlation coefficient was used for determining cross-dating. Experience has shown that for trees growing in the northeastern United States, this method of cross-dating is greatly superior to the traditional skeleton plot technique (Stokes and Smiley 1968). It is also very similar to the highly successful CROS program employed by, for instance, Irish dendrochronologists to cross-date European tree-ring series (Baillie 1982).

COFECHA is used to first establish internal, or relative, cross-dating amongst the individual timbers from the site. This step is critically important because it locks in the relative positions of the timbers to each other, and indicates whether or not the dates of those specimens

with outer bark rings are consistent. Subsequently, the internally cross-dated series are each compared with independently established tree-ring master chronologies compiled from living trees and dated historical tree-ring material. All of the "master chronologies" are based on completely independent tree-ring samples.

In the Brandywine Mansion/Rebecca Lukens House study, species specific, regional composite master chronologies from living trees and historical structures from Eastern Pennsylvania and near-lying regions of Pennsylvania and New Jersey were referenced primarily. All dating results were verified finally by comparison with other independent dating masters from surrounding areas in New York, Maryland, Delaware and northwestern Virginia. In each case, the datings as reported here were confirmed as correct.

Results and Conclusions

The results of the dendrochronological dating of Brandywine Mansion/Rebecca Lukens House timbers are summarized in **Tables 1** and **Figures 1 & 2**. A total of 9 oak samples were analyzed in the laboratory, with all 9 samples providing firm dendrochronological dates. The aforementioned 3 samples collected on site but not submitted to the laboratory for analysis had either significant physical degradation or too few rings for statistically viable analysis.

To achieve these datings required attention during analysis to the previously recorded structural context of the samples (see **Table 1, column 3**). The contextual association of samples from within the structure, the redundancy of the indicated relative cross-datings, and the eventual existence of bark/waney edges demonstrating cutting year, provides the essential constraints necessary for establishing cross-dating, both within a site and with absolute chronological masters. Careful effort is made routinely on-site to confirm, in the absence of the bark itself, the absolute presence of waney edge on the outermost sampled ring of the timbers. Yet due to the in situ condition of the materials and, especially, the anatomical properties of the timbers, it must be considered that there exist in any specific instance a possibility of misevaluation.

The strength of the cross-dating of the samples is indicated by the Spearman rank correlations in the seventh column ("CORREL") of **Table 1**. These statistical correlations, produced by the COFECHA program, indicate how well each sample cross-dates with the mean of the others in the group. The individual correlations vary slightly in statistical strength, but all are in the range that is expected for correctly cross-dated timbers from buildings in the eastern United States.

Of the 9 oak samples that cross-dated well between themselves, and also dated well against the local historical dating master (see **Table 1**, **column 6**), 6 had field verified bark edge at the time of laboratory analysis. The degree of congruency in the achieved datings from the house indicates two construction (or renovation) phases for the building, although neither phase can be assigned conclusively to a specific construction year based solely on the results of the dendrochronological testing:

a phase ("phase 1", see **Table 1**) in 1740, or perhaps just after, as indicated by timbers in this structural unit's garrett and cellar cut in the dormant period of 1738/1739 and after the end of growth dormancy between 1739 and 1740, i.e. cut in the spring of 1740. Regionally, winter dormancy occurs approximately from November to February. The construction date of this unit is likely 1740, since usage of the timbers apparently followed soon after cutting;

a subsequent phase ("phase 2", see **Table 1**) concluded in the final years of the decade of the 1790's (construction likely completed in 1798, perhaps 1799), as indicated by a cutting date after dormancy of year 1797, i.e. cut during spring growth in 1798 and utilized soon thereafter.

Close *in situ* inspection of tool-scarring and the joinery of the timbers indicated that most if not all of these materials were initially utilized soon after cutting, in keeping with historical woodworking and carpentry techniques. Possible re-use of the timbers in subsequent construction phases, although not evidenced directly in the materials, cannot be excluded absolutely. Demonstrable evidence of previously existing structures at these locations is not obvious in the examined material, but cannot be excluded as a possibility.

Table 1. Dendrochronological dating results for samples taken from the Brandywine Mansion/Rebecca Lukens House, Coatesville, Pennsylvania. For WANEY, +BE means the bark edge was present and thought to be recovered at the time of sampling; -BE means that the bark edge was not recovered or was completely missing on the timber. All correlations are Spearman rank correlations of each series against the mean of all of the others of the same species. If the outermost recovered +BE ring is completely formed, it is indicated as "Comp", meaning that the tree was felled in the dormant season following that last year of growth; "Inc" means that the outermost ring was not fully formed, meaning that the tree was felled during the spring/summer growing season of the calendar year following the outermost dated ring.

ID	SPECIES	DESCRIPTION	WANEY	RINGS	DATING	CORREL
BRANDYWINE MANSION PERIOD 1						
RLHCPA01	Oak	Garrett, Period 1, rafter #7 south	+BE	67 Comp	1672 1738	0.41
RLHCPA02	Oak	Garrett, Period 1, collar #3	+BE	137 Comp	1602 1738	0.45
RLHCPA07	Oak	Cellar, Period 1, floor joist, 4th from west wall	+BE	76 Inc	1664 1739	0.54
RLHCPA08	Oak	Cellar, Period 1, joist, 7th from west wall	+BE	69 Inc	1671 1739	0.37
RLHCPA09	Oak	Cellar, Period 1, joist, 5th from west wall	+BE	71 Inc	1669 1739	0.32
BRANDYWINE MANSION PERIOD 2						
RLHCPA03	Oak	Attic, Period 2, rafter #8 north	-BE	52 Inc	1743 1794	0.46
RLHCPA04	Oak	Attic, Period 2, collar #8	-BE	84 Inc	1714 1797	0.45
RLHCPA05	Oak	3rd floor, Period 2, joist, 4th from east wall	+BE	99 Inc	1699 1797	0.47
RLHCPA06	Oak	3rd floor, Period 2, joist, 3rd from east wall	-BE	92 Comp	1697 1788	0.52

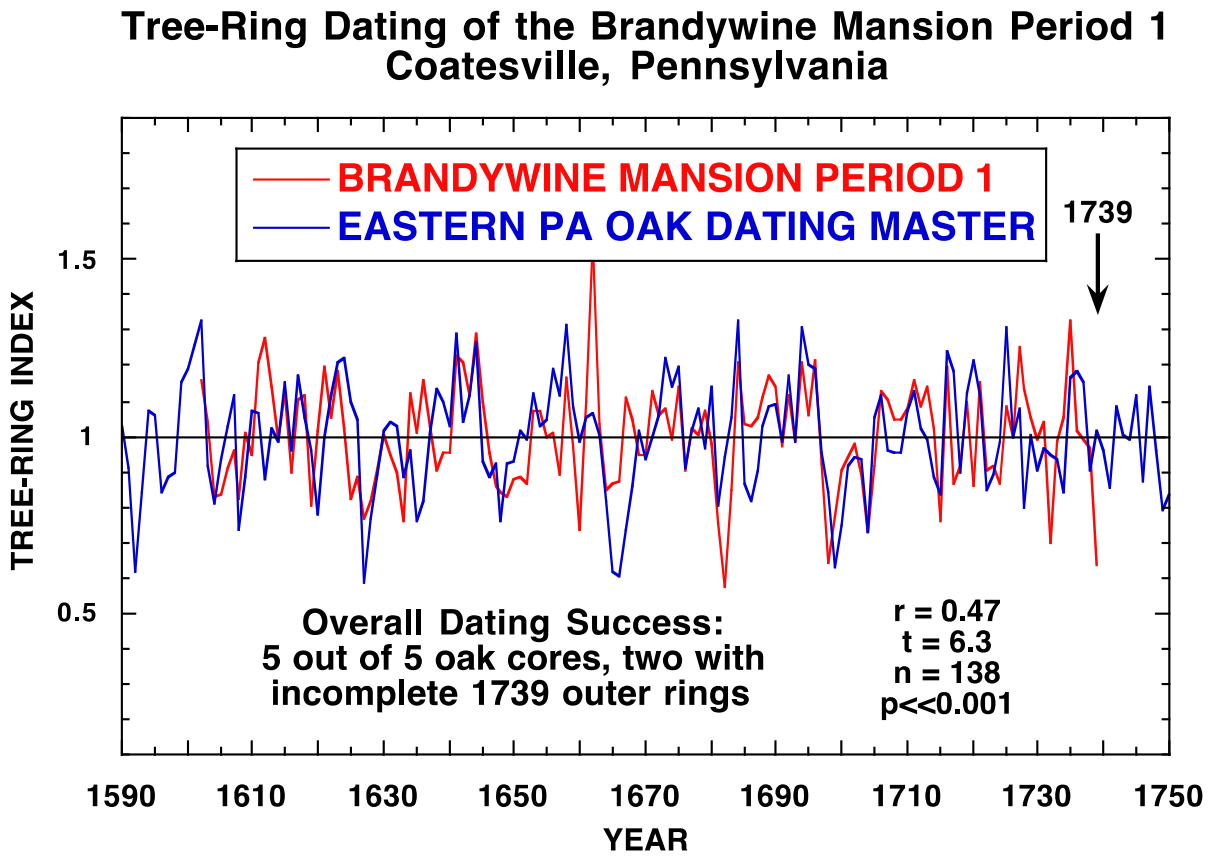


Figure 1. Comparison of the master dated series for the Brandywine Mansion, Period 1, Coatesville, Pennsylvania (red plot) versus an independent eastern Pennsylvania oak dating master (blue plot). Five of five sampled timbers dated, two with felling dates of 1738 (complete outer rings) and three with felling dates of 1739 (incomplete outer rings, i.e. early growth underway in following calendar year). This indicates that the trees were felled in autumn/winter between 1738/39 and in the spring 1740 (beginning of the 1740 growing season). The Period 1 dated master has a highly significant ($p<<0.001$) Spearman rank correlations with the oak dating master.

The "r-factor" is the Spearman rank correlation coefficient, a measure of relative statistical agreement between two groups of measurements or data. It can range from +1 (perfect direct agreement) to -1 (perfect opposite agreement). The "t-value" is Student's distribution test for determining the unique probability distribution for "r", i.e. the likelihood of its value occurring by chance alone. As a rule, a t=3.5 has a probability of about 1 in 1000, or 0.001, of being invalid. Higher "t" values indicate increasingly stronger statistical certitude.

The t-statistics (t=6.3) associated with the correlation between the Brandywine Mansion/Rebecca Lukens House oak series and the regional oak master chronology (r=0.47) is statistically significant ($p<<0.001$) for a 138-year overlap. For that reason, there can be no doubt that the dates presented here for the sampled oak elements of the cellars of Brandywine Mansion/Rebecca Lukens House are valid, and that the statistical chance of the cross-dates being incorrect is far less than 1 in 1000.

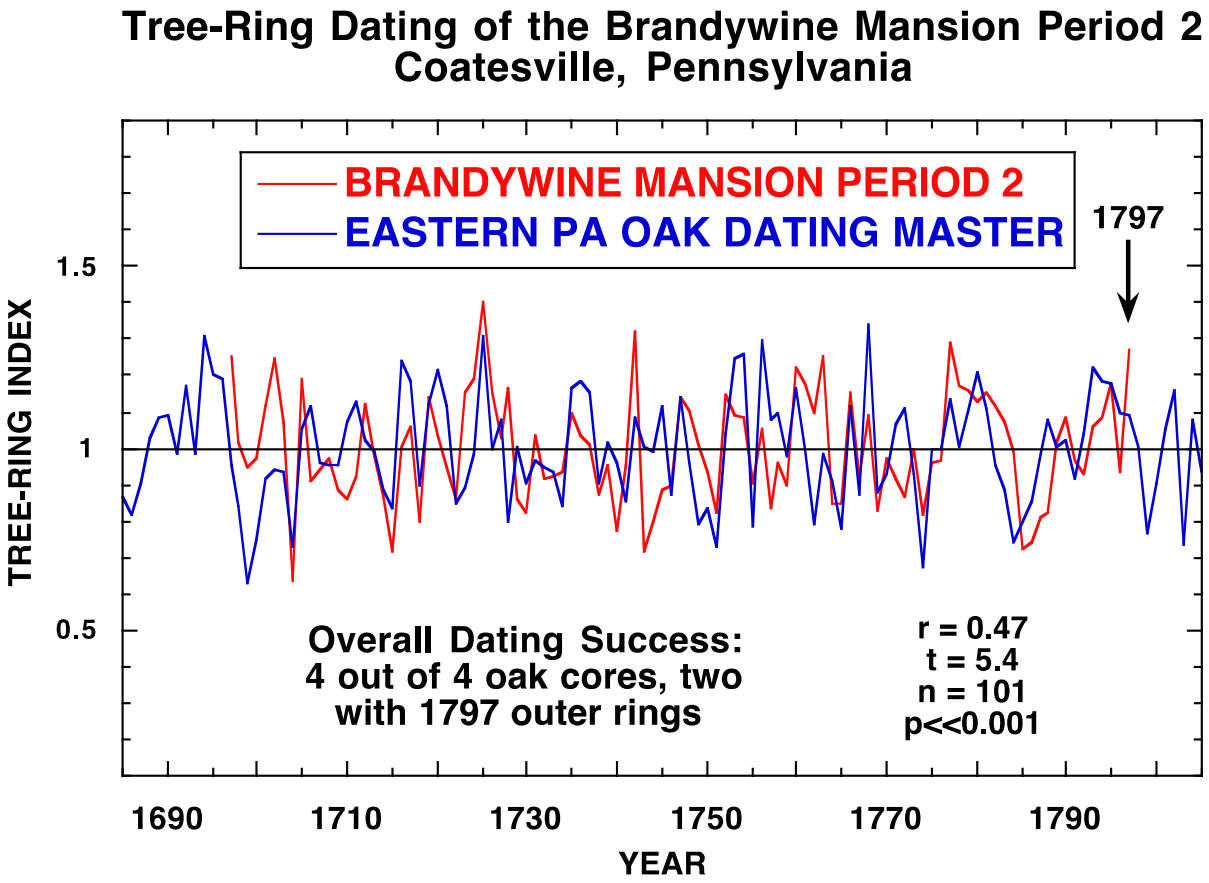
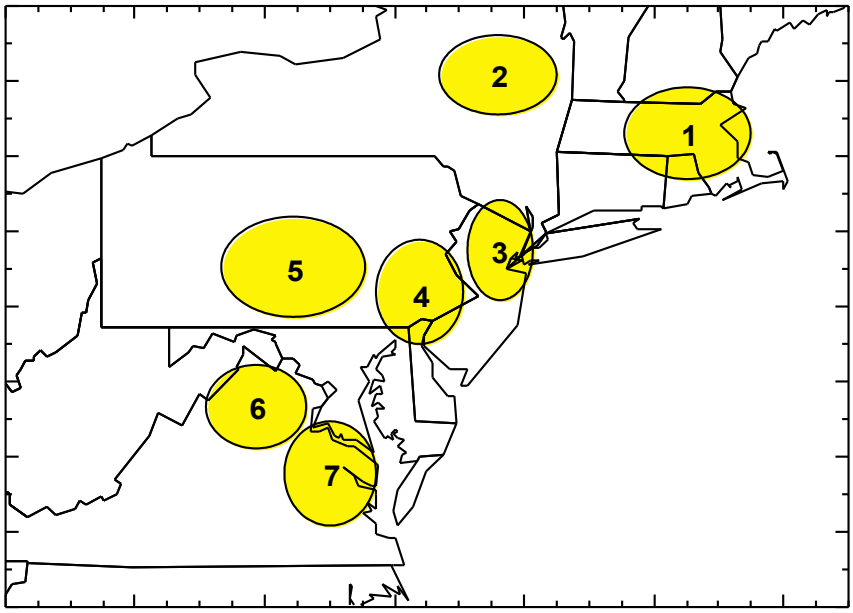


Figure 2. Comparison of the master dated series for the Brandywine Mansion, Period 2, Coatesville, Pennsylvania (red plot) versus an independent eastern Pennsylvania oak dating master (blue plot). Four of four sampled timbers from this period dated, with one having a certain felling date of 1797 (incomplete outer rings, i.e. early growth underway in following calendar year). A second timber with the same 1797 outer date is –BE, so not a felling date. This means that the trees were felled for construction in spring 1798 and/or perhaps slightly after. Other dated timbers in this structural unit provide redundant support for this dating. The Period 2 dated master has a highly significant ($p<<0.001$) Spearman rank correlations with the oak dating master.

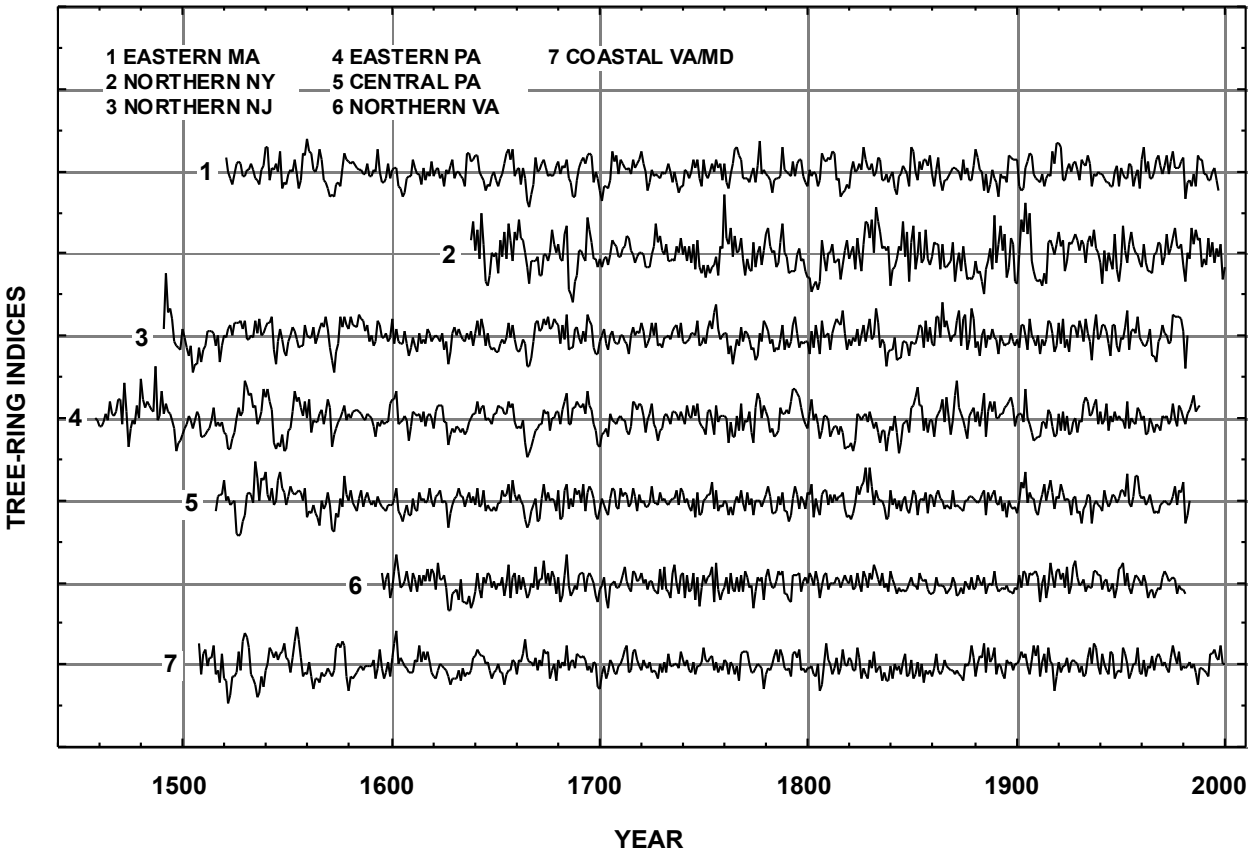
The "r-factor" is the Spearman rank correlation coefficient, a measure of relative statistical agreement between two groups of measurements or data. It can range from +1 (perfect direct agreement) to -1 (perfect opposite agreement). The "t-value" is Student's distribution test for determining the unique probability distribution for "r", i.e. the likelihood of its value occurring by chance alone. As a rule, a t=3.5 has a probability of about 1 in 1000, or 0.001, of being invalid. Higher "t" values indicate increasingly stronger statistical certitude.

The t-statistics (t=5.4) associated with the correlation between the Brandywine Mansion/Rebecca Lukens House series and the regional oak master chronology (r=0.47) is statistically significant ($p<<0.001$) for a 101-year overlap. For that reason, there can be no doubt that the dates presented here for the sampled elements of the cellars of Brandywine Mansion/Rebecca Lukens House are valid, and that the statistical chance of the cross-dates being incorrect is far less than 1 in 1000.

MODERN/HISTORICAL OAK CHRONOLOGIES
REGIONAL LOCATIONS OF SAMPLES



MODERN/HISTORICAL OAK TREE-RING CHRONLOGIES



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Edward Cook was born in Trenton, New Jersey, in 1948. He received his PhD. from the Tucson Tree-Ring Laboratory of the University of Arizona in 1985, and has worked as a dendrochronologist since 1973. Currently director of the Tree-Ring Laboratory at the Lamont-Doherty Earth Observatory of Columbia University, he has comprehensive expertise in designing and programming statistical systems for tree-ring studies, and is the author of many works dealing with the various scientific applications of the dendrochronological method.

William Callahan was born in West Chester, Pennsylvania, in 1952. After completing his military service he moved to Europe, receiving his MA from the University of Stockholm in 1979. He began working as a dendrochronologist in Sweden in 1980 at the Wood Anatomy Laboratory at the University of Lund, and returned to the United States in 1998. A former associate of Dr. Edward Cook at the Tree-Ring Laboratory of Lamont-Doherty, he has extensive experience in using dendrochronology in dating archaeological artifacts and historic sites and structures.

Some regional historical dendrochronological projects completed by the authors:

Abraham Hasbrouck House, New Paltz, NY
Allen House, Shrewsbury, NJ
Belle Isle, Lancaster County, VA
Bowne House, Queens, NY
Carpenter's Hall, Philadelphia, PA
Charpentier House, Philadelphia PA
Christ's Church, Philadelphia, PA
Clifton, Northumberland County, VA
Conklin House, Huntington, NY
Customs House, Boston, MA
Daniel Boone Homestead, Birdsboro, PA
Daniel Pieter Winne House, Bethlehem, NY
Ditchley, Northumberland County, VA
Ephrata Cloisters, Lancaster County, PA
Fallsington Log House, Bucks County, PA
Fawcett House, Alexandria, VA
Gadsby's Tavern, Alexandria, VA
Garrett House, Sugartown PA
Gilmore Cabin, Montpelier, Montpelier Station, VA
Gracie Mansion (Mayor's Residence), New York, NY
Grove Mount, Richmond County, VA
Hanover Tavern, Hanover Courthouse, VA
Harriton House, Bryn Mawr, PA
Hills Farm, Accomack County, VA
Hollingsworth House, Elk Landing, MD
Indian Banks, Richmond County, VA
Indian King Tavern, Haddonfield NJ
Independence Hall, Philadelphia, PA
John Bowne House, Forest Hills, NY
Kirnan, Westmoreland County, VA
Linden Farm, Richmond County, VA
Log Cabin, Fort Loudon, PA
Lower Swedish Log Cabin, Delaware County, PA
Lummis House, Ipswich MA
Marmion, King George County, VA
Martin Cabin, New Holland PA
Menokin, Richmond County, VA
Merchant's Hope Church, Prince George County, VA
Millbach House, Lebanon County, PA
Monaskon, Lancaster County, VA
Morris Jumel House, Jamaica, NY
Frederick Muhlenberg House, Trappe, PA
Nottingham DeWitt House, NY
Old Barn, Madison VA
Old Caln Meeting House, Thorndale, PA
Old Swede's Church, Philadelphia, PA
Panel Paintings, National Gallery, Washington, DC
Pavilion, Ticonderoga, NY
Pennock House & Barn, London Grove, PA
Penny Watson House, Greenwich, NJ
Podrum Farm, Limekiln, PA
Powell House, Philadelphia, PA
Pyne House, Cape May, NJ
Radcliff van Ostrade, Albany, NY
Rippon Lodge, Prince William County, VA
Rochester House, Westmoreland County, VA
Rural Plains, Hanover County, VA
Sabine Hall, Richmond County, VA
Shirley, Charles City County, VA
Sisk Cabin, Culpeper VA
Spangler Hall, Bentonville, VA
Springwater Farm, Stockton, NJ
St. Peter's Church, Philadelphia, PA
Stabler-Leadbeater Apothecary, Alexandria, VA
Strawbridge Shrine, Westminster, MD
Sweeney-Miller House, Kingston, NY
Thomas & John Marshall House, Markham, VA
Thomas Grist Mill, Exton, PA
Thomas Thomas House, Newtown Square, PA
Tuckahoe, Goochland County, VA
Tullar House, Egremont MA
Updike Barn, Princeton, NJ
Varnum's HQ, Valley Forge, PA
Verville, Lancaster County, VA
West Camp House, Saugerties, NY
Westover, Charles City County, VA
Wilton, Westmoreland County, VA
Yew Hill, Fauquier County, VA