Radiocarbon re-dating of contact-era Iroquoian history in northeastern North America

Sturt W. Manning1*, Jennifer Birch2, Megan A. Conger2, Michael W. Dee3, Carol Griggs1, Carla S. Hadden4, Alan G. Hogg5, Christopher Bronk Ramsey6, Samantha Sanft7, Peter Steier8, Eva M. Wild8

A time frame for late Iroquoian prehistory is firmly established on the basis of the presence/absence of European trade goods and other archeological indicators. However, independent dating evidence is lacking. We use 86 radiocarbon measurements to test and (re)define existing chronological understanding. Warminster, often associated with Cahiagué visited by S. de Champlain in 1615–1616 CE, yields a compatible radiocarbon-based age. However, a well-known late prehistoric site sequence in southern Ontario, Draper-Spang-Mantle, usually dated ~1450–1550, yields much later radiocarbon-based dates of ~1530–1615. The revised time frame dramatically rewrites 16th-century contact-era history in this region. Key processes of violent conflict, community coalescence, and the introduction of European goods all happened much later and more rapidly than previously assumed. Our results suggest the need to reconsider current understandings of contact-era dynamics across northeastern North America.

INTRODUCTION

In the earlier to mid-second millennium CE (all dates CE), Northern Iroquoian societies of the northeastern woodlands of North America underwent several major cultural transitions. These include the intensification of agriculture, the development of settled village life, endemic warfare and coalescence into towns, confederacy formation, colonialism, and, lastly, in the 16th century, contact period entry into the global political economy (1, 2). The complete excavation of dozens of sites (3, 4), combined with a vast ethnohistoric literature by early 17th-century explorers and missionaries (5–7), makes the Lower Great Lakes region one of the most robust archeological datasets for theorizing social processes in nonstate societies. Site durations equivalent to one to two human generations (8) make this record ideal for interrogating how the lived experiences of individuals and communities articulate with long-term, macroregional histories. Precise temporal control and the development of finely-grained chronologies are critical to developing and defining community and regional scales of analysis. However, despite a historically informed general narrative, direct historical associations with most sites are lacking for northeastern North America (1–4). One notable exception comes from the visit in 1615–1616 of S. de Champlain, an iconic figure of contact-era northeastern North America whose accounts are central to (re)considerations of violent colonial European interventions (9, 10). He visited a village he named Cahiagué, which has often (but not always) been identified with the Warminster archeological site (Fig. 1 and Table 1) (1, 11, 12). Otherwise, an assumed refined chronology for the late prehistoric period has been based on the initial appearance and then the abundance of types of European trade goods (for example, presence/absence of types of metals and presence/absence of types of glass beads). Relative order of sites before and into the contact era has also been determined from archeological indicators, such as changing percentages of neck and incised decoration on ceramics and types of ceramic smoking pipes (3, 13–16). Standard cultural, social, demographic, economic, and political histories of the Iroquoian peoples; our understanding of indigenous versus European contact dynamics; and associations

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1Cornell Tree Ring Laboratory, Department of Classics, B-48 Goldwin Smith Hall, Cornell University, Ithaca, NY 14853, USA. 2Department of Anthropology, University of Georgia, 250A Baldwin Hall, Jackson Street, Athens, GA 30602-1619, USA. 3Centre for Isotope Research, Faculty of Science and Engineering, University of Groningen, Nijenborgh 6, NL-9747 AG Groningen, Netherlands. 4Center for Applied Isotope Studies, University of Georgia, 120 Riverbend Rd, Athens, GA 30602-4702, USA. 5Radiocarbon Dating Laboratory, University of Waikato, Hamilton 3240, New Zealand. 6Research Laboratory for Archaeology and the History of Art, School of Archaeology, Oxford University, 1 South Parks Road, Oxford OX1 3TG, UK. 7Department of Anthropology, 261 McGraw Hall, Cornell University, Ithaca, NY 14853-4601, USA. 8University of Vienna, VERA Laboratory, Faculty of Physics, Isotope Research and Nuclear Physics, Währinger Straße 17, A-1090 Vienna, Austria. *Corresponding author. Email: sm456@cornell.edu

Fig. 1. Map showing the locations of the four sites investigated in this study in southern Ontario, Canada.
of these processes with wider forces, such as climate change, are written and interpreted on the basis of this accepted chronology ([1–4, 13, 14, 17, 18]; see the Supplementary Materials). The general absence of a direct, independent, and verifiable time frame for this key prehistoric-historic contact era in northeastern North America is problematic, and critical attention is long overdue. Our research seeks to check and better define this contact-era timescale.

The appearances and distribution of European trade goods have conventionally formed the basis of chronology-building from the mid-16th century onward in northeastern North America, and therefore underlie archaeological analyses of all aspects of social, economic, demographic, health, and political change ([1–4, 13, 14, 17, 18]; see the Supplementary Materials). It has been argued that European metals appeared on Iroquoian sites in the mid-16th century and were later followed by glass beads, copper kettles, and other goods that were traded to and otherwise acquired by indigenous individuals and groups ([13, 14]; see the Supplementary Materials). Quantities and types of European materials on indigenous sites have been used to construct timelines such as the glass bead chronology (19–21) or to make assumptions about the chronological ordering of sites based on occurrences and frequencies of European goods (12, 14, 22). Although the dates of manufacture and shipment of certain goods can be identified using European documentary records, associated archeological frameworks are based on the assumption that trade goods were distributed in a distance- and time-transgressive manner. Contemporary perspectives on contact in the 16th and early 17th centuries recognize that there were different modes of participation in, and access to, trade networks (13). These variations resulted in unequal distributions of European-derived goods within and among Iroquoian communities (see the Supplementary Materials), including the outright rejection of European goods and influences ([6], vol. 15, pp. 15–22), rendering such trade good chronologies suspect as region-wide, generalized criteria and frameworks. More widely, there is now a rethinking of contact processes and indigenous consumption of foreign materials across North America. Such studies invariably identify complicated histories of differences both within (e.g., variability among lineages and by rank) and among indigenous communities (1, 2, 23). Thus, in this research, we argue that it is important to use an alternative time frame based on independent evidence—from dendrochronologically calibrated radiocarbon (14C) dating—avoiding interpretative assumptions and logic transfers. Elsewhere in the world, independent absolute chronological time frames (especially 14C) have repeatedly challenged the assumptions of relative chronologies built on expectations about normative chronological distribution patterns and often scarce and nonrepresentative data from trade and cultural exchange (24–30). We therefore test the material culture–based assumptions concerning chronology for contact-era northeastern North America and provide a start toward an independent high-resolution time frame.

We recognize that the existing chronology for contact-era northeastern North America, including both ceramic seriation and trade goods, represents the best efforts over many years by archeologists and historians with the data available to them (see the Supplementary Materials). However, two key developments now mean that an independent high-resolution time frame is possible. First, the accelerator mass spectrometry (AMS) 14C method, enabling 14C dates from small samples and especially on short-lived materials (such as annual-growth plant matter), allows direct dating of relevant (securely associated) archeological contexts (31). Second, the application of Bayesian chronological modeling provides a mathematically coherent framework for integrating 14C dates with prior knowledge from the specific archeological record and securely associated history, permitting us to quantify, constrain, and refine chronological probabilities (31–33). Combined, these two developments create a dating revolution that has opened up a new era of much better defined chronological resolution in archeology across the world (24–33). We report work here using AMS 14C dating incorporating Bayesian chronological modeling to test and investigate the chronology of two key

| Traditional chronology | Archeological phases | Sociocultural characteristics and key events |
|------------------------|----------------------|---------------------------------------------|
| 1000–1300              | Early Iroquoian      | Settlement is in base camps by seasonally mobile populations; limited agriculture. |
| 1300–1350              | Middle Iroquoian     | Small villages, initiation of widespread interaction networks. Migration of early farming communities to the north and east. |
| 1350–1400              |                      | Small- to medium-sized, dispersed villages, extensive interregional interaction. |
| 1400–1450              |                      | Precoalescent; small villages clustered in major drainages. |
| 1450–1500              | Late Iroquoian       | Coalescence; formative aggregate towns, palisaded, with multiple palisade expansions. Some small villages remain, internal conflict within the region. |
| 1500–1550              |                      | Postcoalescent; initial nation formation. Consolidated aggregate towns. All settlements are palisaded, no evidence for expansions. Internal conflict in decline. Interegional interaction increases. |
| 1550–1600              | Protohistoric        | Consolidation of nations. Consolidated aggregate towns (north shore of Lake Ontario), smaller, often unpalisaded village settlements (historic Wendake). Initiation of external conflict. First appearance of European-manufactured metals and glass beads (GBP I, ca. 1580–1600). |
| 1600–1650              | Contact era          | Consolidation of Wendat confederacy. Population clusters in historic Wendake. Consolidated aggregate towns (southern Wendake), smaller village settlements (northern Wendake). Intensification of external conflict. Direct European contact, ca. 1608 (Etienne Brule); ca. 1615 (Champlain); ca. 1630s Jesuit presence increases. In 1650, the Wendat were dispersed by the Haudenosaunee (Iroquois). Extensive presence and diversification of European-manufactured metals and glass beads (GBP II, ca. 1600–1615/1620, GBP III ca. 1615/1620–1650). |
cases for contact-era northeastern North America. The first case, the Warminster site (often associated with Champlain in 1615–1616), offers a case where there is a reasonable basis for an assumed historical association and calendar date association. We thus 14C date this site and assess whether the resultant ages are compatible with the historical association and chronology—and thus whether a refined 14C timescale provides historically useful evidence for contact-era northeastern North America. Our second case is the chronology of a key Wendat community/site relocation sequence in the Rouge River–West Duffins drainage in southern Ontario east of Toronto, Canada. This comprises the sites of Draper, Spang, and Mantle, the largest, most complex completely excavated Iroquoian site in southern Ontario and also known as Jean-Baptiste Lainé (we retain the original site name here as per previous publications) (Fig. 1) (14), which is currently dated ~1450–1550 (Table 1) (3, 14). In this case, there is no clear, direct, historical association. Existing dates have been applied to this sequence based on the absence of European trade goods at Draper and Spang and only three examples of such goods at Mantle. We investigate the timing of these sites via 14C with Bayesian chronological modeling to test both the archeological assumptions (the relative order of the sites as per ceramic seriation) and the assumed calendar dates and offer new 14C-based calendar age estimates for each site.

RESULTS

Here, we present and analyze new and extant radiocarbon (14C) dates obtained on organic samples from the Warminster, Draper, Spang, and Mantle sites to test and investigate the assumed chronology and derived history (see the Supplementary Materials). We obtained samples from each site and use 86 14C dates to achieve independent dating versus the use of assumptions built around trade and cultural traits (tables S1 and S2 and figs. S1 to S3). We focus on short-lived plant remains with direct archeological associations that will provide ages contemporary with use and employ dates on wood charcoal samples to provide terminus post quem (TPQ) constraint information. The latter, despite expected inbuilt age that renders these dates as TPQ constraints, are important for the 16th century because a plateau in the 14C calibration curve in this period (34) can otherwise create dating ambiguities and has been regarded in the past as the problem that hinders precise dating via 14C for Iroquoian archaeology (14, 20).

To begin, we considered the analysis of each site separately. The sites are known to have had occupations typically comprising one to two generations or a few to several decades (8, 14), with the communities then relocating. The Draper site, the Spang site, and then the Mantle site are interpreted as successive iterations of the same ancestral Wendat community (3, 14). We thus initially considered the analysis of the data from each site as a single individual Phase in the OxCal 4.3 Bayesian Chronological Modelling software (32, 35), using the current mid-latitude Northern Hemisphere appropriate IntCal13 14C calibration curve (34). The remains of a tamarack wood post (Larix laricina), WAR-1, associated with House 4 at the Warminster site with 57 preserved tree rings (fig. S4), but missing any indication of outermost tree rings, permitted “wiggle match” 14C dating (36) of a specific sequence of tree-ring samples to define a TPQ for the short-lived material from the Warminster site. In other cases where wood charcoal dates were obtained, we used the Charcoal Outlier (35) or the adapted Charcoal Plus Outlier (30, 37) models to account for inbuilt age in wood charcoal samples versus the other samples on short-lived plant remains from the site Phase. Where multiple dates were run on the same short-lived sample, we used the weighted average (R_Combine in OxCal) but added an additional 8 14C years error term to allow for annual-scale 14C variation (38). We controlled for and down-weighted the influence of outliers among the samples using the General Outlier model in OxCal (35) for short-lived samples (individual dates or the weighted averages), and for the wiggle-match samples, we used the SSimple Outlier model in OxCal (35). We calculated the start and end Boundaries for each site Phase and an overall Date estimate and Span estimate for each Phase and considered any apparent issues (Figs. 2 and 3 and figs. S5 to S7). Where there is an internal sequence within the site Phase from archeological investigation, we also considered models incorporating these known archeological Sequences within the relevant site Phases (figs. S8 and S9 and table S3).

Warminster

The calendar date estimates derived for the Warminster site from the 14C data (Fig. 2) offer most likely 68.2% hpd estimates—overall, these lie between 1585 and 1624—which are compatible with a possible visit to this site by Champlain in 1615–1616. The date range determined does not prove that Warminster = Cahiaqué, but is consistent with this often supported, if not necessarily secure, association (1, 11, 12). In this case, where there is an at least plausible historical association, we may importantly observe that modern AMS 14C dating combined with Bayesian chronological modeling offers a compatible and closely defined date range (see also fig. S5). In this case, as with other work in different areas of the world, both in this general time period (39) and in other time periods (40), AMS 14C dating yields accurate dates against known calendar dates or approximately known historical dates. We may therefore regard 14C dating as an accurate measure of time for the contact-era Iroquoian case.

Draper, Spang, and Mantle

In contrast, the calendar date estimates derived from the analysis of the 14C dates for each of the Draper, Spang, and Mantle sites as independent Phases are completely at odds with the currently accepted chronology and account of Iroquoian late prehistory in the 16th century (Fig. 3). Rather than dating as supposed, ~1450–1500, the Draper and Spang sites most likely date to 1525–1555 and 1513–1593 (57.9%) or 1620–1640 (10.3%), respectively (68.2% hpd ranges). The Mantle site most likely dates to ~1596–1618 (Fig. 3, 68.2% hpd range) (see also figs. S6 to S9 and table S3). This is again much later than its currently accepted date of ~1500–1550.

We concentrate especially on the Mantle case, where we undertook detailed 14C dating, and where the calendar age is perhaps most challenging for the existing chronology (Table 1). As observed when two initial 14C dates were reported from the site, calibrated age ranges on short-lived samples (maize) from the site offered a very wide possible calendar date range from ~1446 to 1462 to 1635 or 1642 at 95.4% probability (14). This wide spread can be attributed to the 14C ages intersecting with the 16th-century plateau in the 14C calibration curve (fig. S3). For this reason, we implemented a strategy aimed at overcoming the ambiguity caused by the shape of the calibration curve to achieve a more precise estimate of the date of the Mantle site. Thus, we dated a range of wood charcoal samples specifically from what are archeologically recognized as early contexts at the Mantle site, as well as a large set of short-lived plant materials from early
Fig. 2. 14C-derived chronology for the Warminster site. (A) The OxCal (32, 35) dating model for the Warminster site Phase with TPQ from a tree ring–sequenced 14C wiggle match on a wood post (36) and then the 14C dates on short-lived plant material, using the IntCal13 14C dataset (34), with the dates on the same plum and bean samples combined (table S5A). The nonmodeled calibrated dating probabilities are indicated by the gray distributions; the modeled probabilities are shown by the black distributions. The lines under the modeled distributions indicate the 68.2% highest posterior density (hpd) and 95.4% hpd ranges. OxCal agreement indices (A, A_model, and A_overall) >60 indicate good agreement between the 14C data and the model. O values are posterior/prior probabilities that the date is an outlier. (B) The modeled Date estimate for the Warminster site from (A). (C) Date estimate from an alternative model treating each date on the plum and bean samples as independent estimates with uniform distributions. The lines under the modeled distributions indicate the 68.2% highest posterior density (hpd) and 95.4% hpd ranges. OxCal agreement indices (A, A_model, and A_overall) >60 indicate good agreement between the 14C data and the model. O values are posterior/prior probabilities that the date is an outlier. (D) As (C) but excluding UGAMS-25451. (A_model and A_overall) values are now >60. The dates of Champlain’s visit to Cahiagué, 1615–1616, are indicated in each panel.

through very late contexts at the site (see the Supplementary Materials). The wood charcoal samples should include, unless they comprise bark or outermost tree rings, an amount of inbuilt age (since the 14C age relates to when the relevant tree rings formed and not to when the tree or branch was cut down and the wood used by humans at the site). None of the wood charcoal samples dated comprise bark or bark edge, and so involve some amount of inbuilt age. We would expect a number of such samples, from a population of such potential samples, to have relatively modest inbuilt ages (coming from outer parts of the original trees or branches—since allometry means typically >50% of the wood in a tree or branch comes from the outer 30% of the tree rings). However, there will also be some samples that have rather older ages, and a few, especially if long-lived tree species are involved, will have much older ages. The Charcoal Outlier model (35) and Charcoal Plus Outlier model (30, 37) in OxCal seek to represent this prior knowledge. In the Mantle case, the charcoal samples are key to discerning the chronological placement. Were Mantle to date ~1500–1550 as the existing traditional chronology holds (Table 1), then the somewhat older and much older charcoal samples from early contexts at the site should extend from the earlier 16th century and back across the 15th century, and so would increasingly reflect the preplateau (much older) 14C ages of the 15th century. However, most of the dates on the charcoal samples do not do this. Instead, they offer calendar ages similar to those from the short-lived plant materials, and thus in the 16th century to the later 16th century to the start of the 17th century (fig. S3B). Given the inbuilt age involved, and the fact that these samples come from early contexts at the Mantle site, these dates on the charcoal samples are TPQ values, generally for Mantle, and very particularly for the later contexts at the site. These TPQ ranges constrain the possible placement of the dates on the short-lived plant material from Mantle and resolve the previous 16th-century ambiguity. Since the dates on the charcoal samples are TPQ ages by varying amounts and, note, for early contexts at Mantle, we have to find a solution whereby within the available dating probability, the dates on the charcoal samples lie earlier than the dates on the short-lived samples (and certainly
those from the later contexts at Mantle). The only solution is for the TPQ dates on the charcoal samples to lie in the period before, or into, the late 16th century, whereas the dates on the short-lived plant materials lie in the period from the later 16th century to the early 17th century. The OxCal modeling of this situation quantifies a resolved, precise date for the Mantle site (Fig. 3 and fig. S9).

We then implemented an analysis using the Order function in OxCal (32) to determine the probabilities of the relative temporal order of the three sites, Draper, Spang, and Mantle, based solely on the $^{14}$C data (see the Supplementary Materials). This resulted in a chronological sequence, with Draper determined as likely older than both Spang ($P = 0.56$) and Mantle ($P = 0.67$) and with Spang determined as likely older than Mantle ($P = 0.63$) (table S4). This $^{14}$C-determined relative site sequence of Draper, then Spang, and then Mantle is exactly consistent with, but entirely independent of, existing relative archeological assessment. These archeological assessments are based on changing material culture traits, including seriation of ceramic decorative traits, seriation of changes in pipe form, and absence/presence of European-manufactured goods. Such analysis had previously proposed the same relative temporal order of the three sites: Draper, then Spang, and then Mantle (3, 14, 16).

Since we now have a definite, independently verified, relative order among the three sites, Draper, Spang, and Mantle, we therefore consider a Bayesian Sequence model (32) using the data and Phase models in Fig. 3 to determine the best calendar age estimates for these three sites in view of this additional prior knowledge. Because we assume that the three sites are successive iterations of the same community (3, 14), and thus the end of one site will have overlapped with the beginning of its successor, we used trapezoidal phases to permit the consecutive Phases to overlap (Fig. 4 and Table 2) (41). The analysis neatly resolves a site sequence within the overall period ~1530–1615 (68.2% hpd ranges), completely at odds with the previously accepted chronology of ~1450–1550.

**DISCUSSION**

Our data and analyses indicate a revised absolute chronology for the sites we investigated and, by implication, raise important questions
about wider chronology in the pre- and early contact-era periods in northeastern North America that now require investigations of the type undertaken for the four cases in this paper. The revised dates for the Draper, Spang, and Mantle sequence already suggest substantial changes in the previous understandings of the pace and timing of indigenous social, economic, and political changes in northeastern North America, such as processes of coalescence and conflict, substantially shortening the previously assumed time frame and moving these transformations later into the contact-era period in the 16th century. While our modeling and results accord with the relative seriation of ceramic decorative motifs as currently understood, additional efforts need to be directed toward the assessment of ceramic chronologies through independently verifiable means. The fact that the chronology based on the presence/absence of trade goods has been found to be so much in error, by ~50–100 years, raises fundamental questions about the role of European contact in transforming or influencing fluctuations in indigenous economic and sociopolitical networks during the 16th century (see the Supplementary Materials). In particular, such questions focus around the timing of the appearance and distribution of European-manufactured items at indigenous sites and whether finds and frequencies of such items can be used as a reliable temporal measure by archeologists. Until now, the general underlying assumption has been that European trade goods were distributed in a regular fashion throughout ancestral Wendat territory (42). However, this must now be questioned with the new understanding that occupation at Mantle and Warminster may have been at least partly contemporary (fig. S10), with the former containing scant European-derived metals and the latter containing a substantial assemblage of both European metals and glass beads. Critical approaches, along with archeological and ethnohistorical examples, point to variations and even conflict over access to or participation in trade of European goods, or groups blocking access to such goods and networks, or of some indigenous groups rejecting European contact and goods ([6], vol. 15, pp. 15–22; [13, 23, 43–45]). In addition, the revised chronology has relevance for how developments in Iroquoia may be associated with climate: the transformative coalescent and postcoalescent Phases ([3, 14]; see the Supplementary Materials) now occur across the peak of the Little Ice Age (LIA) from the mid-1500s to the early 1600s and not across the previous century or so. Just as White (18) carefully correlates and elucidates the European encounter with North America with this peak LIA era, so do key transformations in Iroquoian
societies—especially the intensification of conflict and confederacy formation [(3, 22); see the Supplementary Materials]—correlate with this same particularly challenging climate period. Looking more widely across North America, our data indicate the urgent need now for new sustained efforts at modern, independent chronological building, using science-based methods, which have the power to transform traditional archeological narratives and to highlight issues of agency and historical contingency in the late prehistoric and early colonial eras.

Some caveats and comments on future developments are in order by way of conclusion. We note that our study uses data from only four sites. We selected Warminster as one of the only Iroquoian sites with an often-proposed direct historical association to investigate and confirm that $^{14}$C dating could and should offer independent but compatible information and with reasonably good precision. The other three sites offer a well-known site relocation sequence from the supposed Late Iroquoian period before substantial European contact (Table 1) (3, 14). Needless to say, to now test and further establish the wider relevance of the revised chronological implications suggested by our results, additional $^{14}$C dates need to be obtained and analyzed from samples from a variety of other Iroquoian (and related) sites in northeastern North America to create a wider chronological (re)understanding. In particular, the methods we use have the potential to resolve the previous problem of a lack of subcentury resolution for the 16th century, which has been noted as a limiting problem for the field until now (13). The accuracy of the calibrated $^{14}$C dates is of course central to the validity of the chronology presented here. We have run $^{14}$C dates at several different laboratories, each using slightly varying methods, and obtained compatible $^{14}$C ages for similar or the same samples and contexts (table S1); thus, the $^{14}$C dates we report appear generally robust (see the Supplementary Materials). The calendar dates determined from these $^{14}$C ages depend on the accuracy of the $^{14}$C calibration curve for the mid-latitude Northern Hemisphere in this period (34). Available data from known-age mid-latitude Northern Hemisphere material indicate findings for the mid-second millennium largely compatible with the IntCal13 dataset (38, 39, 46–48), in support of the accuracy of the approximate range of the calibrated calendar age estimates presented here. However, it should be noted that future revisions of the calibration curve, particularly as additional annual resolution data become available, may lead to minor (likely <10 to 20 years) revisions.

We must also highlight that some flexibility remains. The 68.2% and 95.4% modeled calendar age ranges in Figs. 2 to 4 and Table 2 are as stated: ranges within which the dated elements lie according to these probability levels. Thus, to take the most notable example above, the modeled ages suggest that the Mantle and Warminster site occupations may be at least partially contemporary (Figs. 2 to 4 and fig. S10). This may well be the case, but it is also still possible within the modeled calendar age ranges and probabilities that, for example, the Mantle site ended before ~1615–1616, when Champlain stayed at Cahiagué, and for Warminster to date so as to include Champlain’s stay. Critics will undoubtedly query how, for example, the Warminster site has a substantial assemblage of European trade goods, but Mantle does not, if Mantle is of similar or even contemporary date (and this was of course part of the reason the Mantle site was previously dated ~1500–1550). We also acknowledge that the Mantle site contained a diverse ceramic assemblage interpreted as representing an extensive interaction network (14), and that this raises questions about why those interactions may not have included the acquisition of more European-manufactured materials. Aware of such concerns and previous expectations, we undertook a detailed dating program specifically to resolve Mantle’s placement within the overall 16th-century plateau in the $^{14}$C calibration curve as discussed above. Both in isolation and as part of the Draper-Spang-Mantle sequence, we found that Mantle lies in the late 16th to the early 17th century, some 50 to 100 years later than previously thought, and thus it is at least close to or even contemporary with the Warminster site (Figs. 3 and 4 and figs. S6, S7, S9, and S10). In such a case, confronted by the differences in trade goods recovered, we must instead reflect on the very different trade histories, routes, and connections of sites and areas in the greater northeastern North American region. These differences relate to both temporal and spatial dimensions, as well as the social dimension reflecting differences in how such goods were used and valued and deposited across different social groupings (for example, Ontario Iroquoian evidence of European trade goods in earlier periods largely comes from mortuary contexts) (13). These differences

### Table 2. The calendar date ranges (or periods) determined for selected Dates, Spans, and Boundaries in the Draper-Spang-Mantle site sequence model shown in Fig. 4 and compared with a rerun of this model but using (i) the Charcoal Plus Outlier model (30, 37) and (ii) after excluding the six minor possible outliers noted in the Supplementary Materials and fig. S5. This rerun model runs with typical values of $A_{\text{test}}$ of 86.5 and $A_{\text{average}}$ of 84 each above the satisfactory threshold value of 60. Calendar dates CE in regular font, calendar years (duration) in italics.

| Model                  | Start Draper | Date Draper | Span Draper | Mid end Draper | Duration end Draper | Mid start Spang | Date Spang | Span Spang | Mid end Spang | Duration end Spang | Mid start Mantle | Date Mantle | Span Mantle | End Mantle |
|------------------------|--------------|-------------|-------------|----------------|---------------------|-----------------|------------|------------|----------------|-------------------|------------------|-------------|-------------|------------|
| First model            | 1523–1539    | 1517–1551   | 1522–1540   | 1515–1553      | 0–5                 | 0–19            | 1551–1577  | 4–23       | 1551–1590    | 0–7               | 1593–1608         | 1599–1614  | 2–19        | 1604–1618  |
| Rerun revised model    | 1528–1544    | 1523–1555   | 1527–1544   | 1521–1557      | 1–13                | 0–25            | 1531–1550  | 0–6        | 1535–1580    | 0–5               | 1532–1549         | 1532–1549  | 1532–1549   | 1532–1549  |

Figure 4 model
68.2% hpd 95.4% hpd 68.2% hpd 95.4% hpd

End Mantle 1604–1618 1599–1631 1604–1618 1596–1631

Draper-Spang-Mantle site sequence model shown in Fig. 4 and determined for selected Dates, Spans, and Boundaries in the Table 2. The calendar date ranges or periods (in calendar years) in italics.
MATERIALS AND METHODS
Experimental design
Organic samples comprising short-lived (annual-growth) plant materials and wood or wood charcoal were selected and obtained from the collections from four archeological sites from northern Iroquoia (Ontario, Canada): Warminster, Draper, Spang, and Mantle (Fig. 1). These materials were examined and 14C dated to provide independent age estimates of the samples and sites and to allow testing and comparison of these age estimates versus existing dates determined largely from culture-historical approaches (Table 1). The 14C ages from each of the sites were then analyzed. The first step involved the analysis of each site group as separate (i.e., independent) site Phases using the OxCal software (32) and the IntCal13 14C calibration dataset (34). The second step for the three sites, Draper, Spang, and Mantle, argued to belong to successive iterations of the same community, was analysis via the OxCal Order function to determine the likely chronological order of the three sites. The third step, in the case of these three sites understood from archeological investigation to form a successive series of site relocations by the same community, since the analysis of the 14C data independently confirmed this assumption, was analysis of the three sites as a Sequence using the Bayesian probability methods available in the OxCal software (32). This should yield best (most resolved) age estimates, since the analysis involves multiple constraints within such a Sequence analysis. Since the successive site occupations are assumed to be contiguous, we assumed that it is likely that the ends and beginnings of the successive site occupations were at least partly overlapping, and so we employed a model assuming trapezoidal Phases (41).

Archeology
A summary discussion of the archeological sites and data used in this study is provided in the Supplementary Materials.

Dendrochronology
Sample WAR-1, House 4 Feature 13 post, from the Warminster site comprised an L. liricina sample comprising in all 57 extant tree rings. The outer rings to the original bark of the sample were not preserved. The sample was prepared for dendrochronological study and the tree rings were measured (fig. S4). Five defined tree-ring segments, comprising tree rings 9 to 17, 19 to 27, 29 to 37, 39 to 47, and 49 to 57, were dissected from the sample with a steel blade under a binocular microscope and 14C dated. The resultant tree-ring-sequenced 14C dates were then wiggle matched (36) to obtain a best calendar age estimate for the final extant tree ring, ring 57, which sets a TPQ for the original cutting date and use of the sample.

Radiocarbon (14C) samples and dates
Details on the samples and the 86 14C dates used in this paper (from 90 original dates, 4 excluded, see table S1) and a summary of the methods used at each of the four laboratories are provided in the Supplementary Materials.

Calibration and Bayesian chronological modeling
Calibration and Bayesian chronological modeling used the OxCal software (32) and forms of outlier analysis (30, 35, 37) and the IntCal13 14C calibration dataset (34), with curve resolution set at 1 year. We used capitalized forms of words such as Sequence, Phase, Boundary, Date, Span, and Order to refer to OxCal terminology. The models and elements are described in the Supplementary Materials and shown in Figs. 2 to 4 and figs. S6 to S11, and the OxCal runfiles for Figs. 2 to 4 and figs. S8 and S9 are listed in tables S5 to S9. We note that for reasons of space and legibility in the figures, we did not include the OxCal keywords. Please refer to the OxCal runfiles in tables S5 to S9 for the full model specifications. (Note: OxCal assumes that IntCal13, the current Northern Hemisphere 14C calibration curve at the time of writing, is the calibration dataset to use, and this does not need to be specified.) Details on the Bayesian chronological modeling are provided in the Supplementary Materials.

SUPPLEMENTARY MATERIALS
Supplementary material for this article is available at http://advances.sciencemag.org/cgi/content/full/4/12/eaav0280/DC1

Supplementary Materials and Methods
Fig. S1. A comparison of the 14C ages (conventional radiocarbon years before the present [BPI]) reported on samples of short-lived plant remains in table S1 by site (excluding the four dates with problematic Δ13C values—see table S1).
Fig. S2. The nonmodeled, individual, calibrated calendar dating probability ranges for the 14C dates reported in table S1 (excluding the four with problematic Δ13C values—see table S1).
Fig. S3. The nonmodeled, individual, calibrated calendar dating probability ranges for the 14C dates reported in table S1 shown against the IntCal13 calibration curve and the (nonmodeled) calibrated age probabilities for the subset of dates on samples just from Mantle early contexts.
Fig. S4. Photos and ring-width measurements, WAR-1 sample.
Fig. S5. Comparison of the 14C range (overall 1σ) of the set of 14C dates on short-lived plant remains from Warminster (see table S1) against the modeled (mid-point) and raw (constituent) IntCal13 (34) data (shown with 1σ errors) (raw data from: http://intcal.qub.ac.uk/intcal13/3) placed within the calendar period, ~1596–1619, identified in the analysis reported in Fig. 2.
Fig. S6. Results from an alternative run of the dataset in Fig. 3 as summarized in Fig. 3B, but using the Charcoal Plus Outlier model.
Fig. S7. Results from an alternative run of the dataset in Fig. 3 as summarized in Fig. 3B but after excluding the six minor possible outliers identified by the SSimple outlier model in the various R. Combines (VERA-6268 0:8/5, OxA-33079 0:8/5, VERA-6215_2 O:12/5, VERA-6219 O:12/5, OxA-33082 O:16/5; and VERA-6217 O:6/5).
Fig. S8. Revised model of the Spang site data as a Sequence with the Midden 2 Level 4 date treated as earlier than the Phase of Midden 2 Level 3 dates.
Fig. S9. Revised model of the Mantle site as a Sequence using those samples best associated with the intrasite phasing.
Fig. S10. Comparisons of the Warminster Date Estimate probability density function (PDF) from Fig. 2D with the Date Mantle PDF from Fig. 3.
Fig. S11. Comparison of the PDfs for the Date Mantle estimate from 10 runs of the Mantle model in Fig. 3.
Table S1. The samples and conventional radiocarbon dates used in this study.
Table S2. UGAMS radiocarbon dates on the Warminster Feature 12 Prunus Americana (plum) sample using several different pretreatment approaches (data as listed in table S1).
of the Upper Paleolithic site at Krems-Hundssteig in Lower Austria. Radiocarbon, 5–16 (2004).

Glass beads and the early contact period huron ball site. (1995).

E. W. Fitzgerald, D. H. Knight, A. Bain, Untangleurs of matters temporal and cultural: Glass beads and the early contact period huron ball site. Can. J. Archaeol. 19, 117–138 (1995).

E. E. Jones, Spatiotemporal analysis of old world diseases in North America, A.D. 1519–1807. Am. Anthropol. 79, 487–506 (2014).

A. L. Hawkins, J. A. Petrus, L. M. Anselmi, G. Crawford, Laser ablation-inductively coupled plasma-mass spectrometry analysis of copper-based artifacts from Southern Ontario and the chronology of the indirect contact period. J. Archaeol. Sci. Rep. 6, 332–341 (2016).

K. A. Jordan, Colonies, colonialism, and cultural entanglement: The archaeology of postcolumbian intercultural relations, in International Handbook of Historical Archaeology, T. Majewski, D. Gaimster, Eds. (Springer, 2009), pp. 31–49.

Chapdelaine, Saint Lawrence Iroquoians as middenmakers or observers: Review of evidence in the Middle and Upper Saint Lawrence Valley, in Contact in the 16th Century: Networks among Fishers, Foragers, and Farmers, B. Loewen, C. Chapdelaine, Eds. (University of Ottawa Press, 2016), pp. 149–170.

L. A. Pavlish, K. Michielski, J.-F. Moreau, R. M. Farquhar, W. Fox, L. M. Anselmi, C. Garrad, C. Walker, G. Warrick, D. Knight, S. Aufreiter, R. G. V. Hancock, Tracing the distribution of late 16th and early 17th century European copper artefacts in Southern Québec and Ontario, Canada. Archaeometry 60, 517–534 (2018).

J. O. Berger, Bayesian analysis: A look at today and thoughts of tomorrow. J. Am. Stat. Assoc. 95, 1269–1276 (2000).

C. E. Buck, W. G. Cavanagh, C. D. Litton, Bayesian Approach to Interpreting Archaeological Data (Wiley, 1996).

C. E. Buck, M. Juarez, Bayesian radiocarbon modelling for beginners. arXiv:1704.07141 [stat.AP] (24 April 2017).

H. T. Waterbolk, Working with radiocarbon dates. Proc. Prehist. Soc. 37, 15–33 (1971).

W. G. Mook, H. J. Steurman, Physical and chemical aspects of radiocarbon dating. PACT 8, 31–55 (1983).

W. Lacker, G. Bonani, M. Friedrich, I. Hajdas, B. Kromer, N. Nemec, M. Ruff, M. Suter, H.-A. Synal, C. Vockenhuber, MICADAS: Routine and high-precision radiocarbon dating. Radiocarbon 52, 252–262 (2010).

F. Brock, T. F. G. Higham, P. Ditchfield, C. B. Ramsey, Current pretreatment methods for AMS radiocarbon dating at the Oxford Radiocarbon Accelerator Unit (ORAU). Radiocarbon 52, 103–112 (2010).

M. Dee, C. B. Ramsey, Refinement of Graphite Target Production at ORAU Proceedings of 8th AMS Conference Vienna, Elsevier Science Publishers. Nucl. Instrum. Methods Phys. Res. B 172, 449–453 (2000).

C. B. Ramsey, T. F. G. Higham, P. Leach, Towards high-precision AMS: progress and limitations. Radiocarbon 46, 17–24 (2004).

R. A. Staff, L. Reynolds, F. Brock, C. B. Ramsey, Wood pretreatment protocols and measurement of tree-ring standards at the Oxford Radiocarbon Accelerator Unit (ORAU). Radiocarbon 56, 709–715 (2014).

S. W. Manning, C. Griggs, B. Lorentzen, C. B. Ramsey, D. Chivall, A. J. Timothy Jull, T. E. Lange, Fluctuating radiocarbon offsets observed in the southern Levant and implications for archaeological chronology debates. Proc. Natl. Acad. Sci. U.S.A. 115, 6141–6146 (2018).

A. Cherkinsky, R. A. Culp, D. K. Dvoracek, J. E. Noakes, Status of the AMS facility at the University of Georgia. Nucl. Instrum. Methods Phys. Res. B 268, 867–870 (2010).

J. S. Vogel, J. R. Southon, D. E. Nelson, T. A. Brown, Performance of catalytically condensed carbon for use in accelerator mass spectrometry. Nucl. Instrum. Methods Phys. Res. B 5, 289–293 (1984).

E. M. Wild, C. Neugebauer-Maresch, T. Einwögerer, P. stadler, P. Steier, F. Brock, 14C dating of the Upper Paleolithic site at Krems-Hundsstein in Lower Austria. Radiocarbon 50, 1–10 (2008).

P. Steier, F. Dellingwer, W. Kutschera, W. Rom, E. M. Wild, Pushing the precision of 14C measurements with AMS. Radiocarbon 46, 5–16 (2004).

E. M. Wild, P. Steier, P. Fischer, H. Höflmayer, 14C dating of humic acids from Bronze and Iron Age plant remains from the eastern Mediterranean. Radiocarbon 55, 599–607 (2013).

F. Dellingwer, W. Kutschera, K. Niculiscu, Peter Schilling Peter Steier, E. M. Wild, 14C calibration with AMS from 3500 to 3000 BC, derived from a new high-elevation stone-pine tree-ring chronology. Radiocarbon 46, 969–978 (2004).

S. W. Manning, C. B. Griggs, B. Lorentzen, G. Barja, C. B. Ramsey, B. Kromer, E. M. Wild, Integrated tree-ring-radiocarbon high-resolution timeframe to resolve earlier second millennium BCE Mesopotamian chronology. PLOS ONE 11, e0157144 (2016).

C. B. Ramsey. Radiocarbon calibration and analysis of stratigraphy: The Oxcal program. Radiocarbon 37, 425–430 (1995).

C. B. Ramsey, S. Lee, Recent and planned developments of the Program Oxcal. Radiocarbon 55, 720–730 (2013).

A. Bayliss, Quality in Bayesian chronological models in archaeology. World Archaeol. 47, 677–700 (2015).

W. D. Hamilton, A. M. Krus, The myths and realities of Bayesian chronological modeling revealed. Am. Antiquity 83, 187–203 (2018).

S. Lee, C. B. Ramsey, A. Mazar, Iron Age chronology in Israel: Results from modelling with a trapezoidal Bayesian framework. Radiocarbon 55, 731–740 (2013).

M. Galimberti, C. B. Ramsey, S. W. Manning, Wiggle-match dating of tree ring sequences. Radiocarbon 46, 917–924 (2004).

G. K. Ward, S. R. Wilson, Procedures for comparing and combining radiocarbon age determinations: A critique. Archaeometry 20, 19–31 (1978).

T. Higham, K. Douka, R. W. C. Ramsey, F. Brock, L. Baseli, M. Camps, A. Arrizabalaga, J. Baena, C. Barroso-Ruiz, C. Bergman, C. Boitard, P. Boscato, M. Caprarós, N. J. Conard, C. Drai, A. Froment, B. Galván, P. Gambassini, A. Garcia-Moreno, S. Gimbal, P. Huesaerts, B. Holt, M.-J. Iaroti-Chiapuso, A. Jelinek, J. F. J. Pardo, J.-M. Maillo-Fernández, A. Maron, J. Maroto, M. Menéndez, L. Metz, E. Morin, A. Moroni, F. Negrino, E. Panagopoulou, M. Peresani, S. Pinson, M. de la Rasilla, R. Jael-Salvatore, A. Ronchetti, D. Santamaria, P. Serral, S. Slimak, J. Soler, N. Soler, A. Villaluela, R. Pinhasi, R. Jacobi, The timing and spatiotemporal patterning of Neanderthal disappearance. Nature 512, 306–309 (2014).

M. B. Schiffler, Radiocarbon dating and the “old wood” problem: The case of the Hohokam chronology. J. Archaeol. Sci. 13, 13–30 (1986).

M. Stuiver, H. A. Polach, Reporting of 13C data. Radiocarbon 19, 355–363 (1977).

J. P. Hart, W. A. Lovis, J. K. Schellenberg, G. R. Urquhart, Paleodietary implications from stable carbon isotope analysis of experimental cooking residues. J. Archaeol. Sci. 34, 804–813 (2007).

D. Creel, A. Long, Radiocarbon dating of corn. Am. Antiquity 51, 826–837 (1986).

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Radiocarbon re-dating of contact-era Iroquoian history in northeastern North America
Sturt W. Manning, Jennifer Birch, Megan A. Conger, Michael W. Dee, Carol Griggs, Carla S. Hadden, Alan G. Hogg, Christopher Bronk Ramsey, Samantha Sanft, Peter Steier and Eva M. Wild

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