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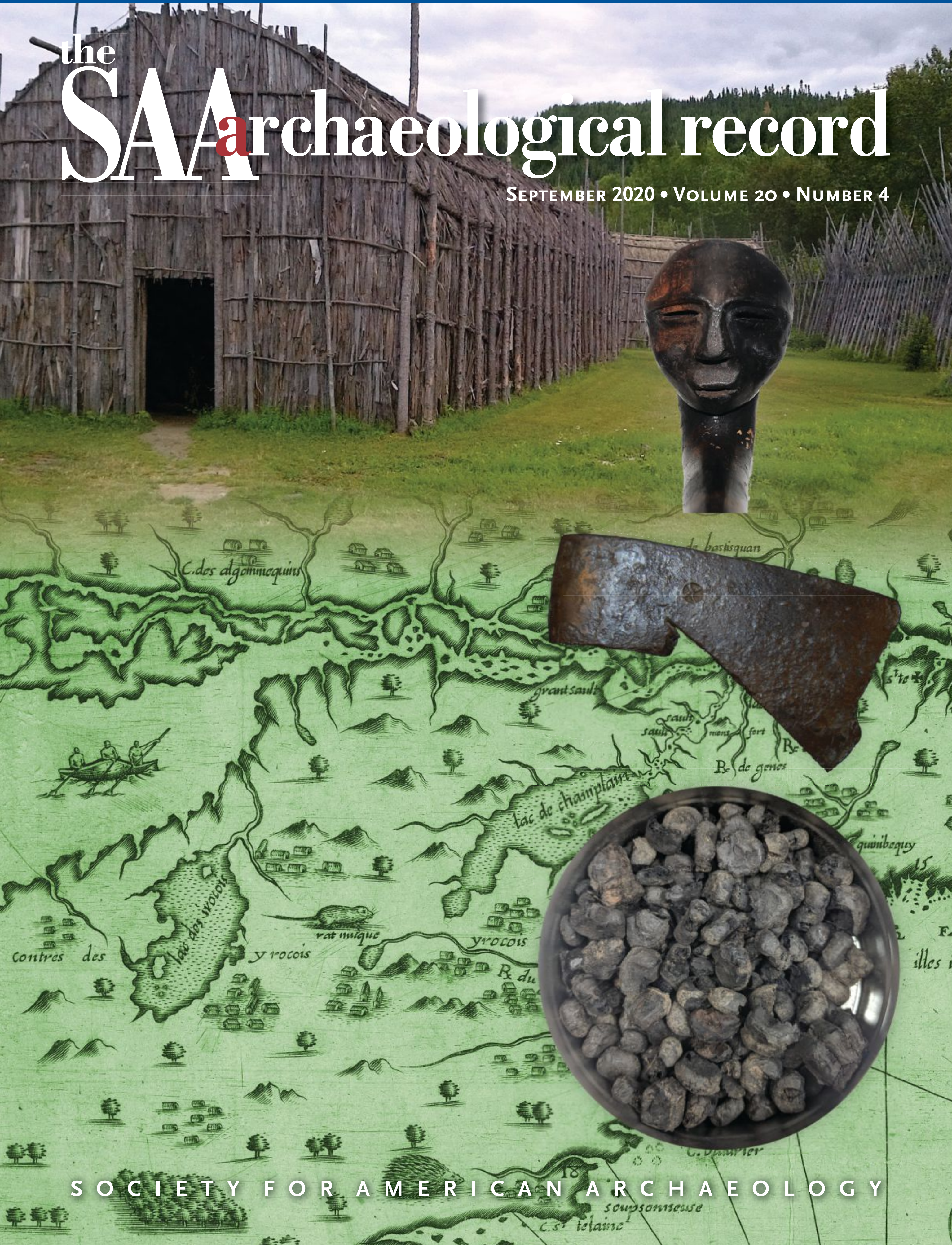

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the SAA archaeological record

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RADIOCARBON DATING, BAYESIAN MODELING, AND AMERICAN ARCHAEOLOGY

2020

Sturt W. Manning

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Radiocarbon Dating Today

Radiocarbon dating has been a key part of archaeology for 70 years. Once regarded as approximate but invaluable for prehistory where dates were broad, in the intervening decades the technique has achieved significant further resolution in three ways. First, despite initial assumptions, it was realized that atmospheric radiocarbon levels vary through time, and so, to be used for dating, radiocarbon measurements need to be calibrated against a known-age record. Luckily, various tree species that provide one growth ring per year offered a solution, and decades of work have provided a calibration curve allowing us to turn radiocarbon measurements into accurate calendar age estimates. Today, with the release of the IntCal20 radiocarbon calibration curve (Reimer et al. 2020; see Figure 1), we have secure known-age tree-ring-based data back (from AD 1950) for 12,310 years, the first 4,998 years at annual resolution, and the overall calibration record—using a mixture of approximately placed tree rings and data from speleothems (stalagmites), plant remains from laminated lake sediments, and corals—extends back 55,000 years. In special circumstances, the annual resolution now available for the last 5,000 years can even enable radiocarbon-based dating at annual, and even subannual, resolution (Kuitems et al. 2020). Second, since the advent of accelerator mass spectrometry (AMS) radiocarbon dating, tiny samples can now be dated (mg versus grams, and originally tens of grams). This permits the routine dating of specific small samples (like seeds) or tiny fragments from museum objects (so minimally destructive) and is even starting to allow compound specific dating of particular residues—for example, such as those extracted from ancient ceramics informing us about food practices and storage (Casanova et al. 2020). Third, the development of Bayesian chronological modeling approaches, whereby prior knowledge (about stratigraphic, site, and intersite relationships, cultural associations, genetic associations, and historical information) can be integrated with radiocarbon dating probabilities in order to obtain and test refined and more robust timeframes. This approach has dramatically changed dating possibilities and the questions we may ask and increased chronological resolution for the past. For example, placing prehistory securely and precisely in time allows not only regional-scale comparisons—for example, with high-resolution paleoclimate records—but also local site and individual lived-history scales of analysis. Application of this revolution has been led by the development and now widespread use of various software packages, especially OxCal (https://c14.arch.ox.ac.uk/oxcal.html), developed by Christopher Bronk Ramsey at the University of Oxford.

Radiocarbon dating in 2020 thus has a power and reach far beyond its initial ambition of approximate dates for prehistory. Large projects invariably bringing together teams of complementary specialists to address the several interlocked aspects from archaeology and paleobotany to chemistry, physics, and genetics, as well as statistics and other areas, and employing many dozens to hundreds or even thousands of radiocarbon dates integrated with the available prior knowledge from careful investigation of archaeological sequences and related information are enabling the definition and resolution of key events, processes, patterns, and rates of change especially over the last 12,000 years with unprecedented clarity. Even several thousand years ago, we can hope to define specific contexts into the scale of several decades to a half century or so—the timespan of a lived human life in the past. In other words, an historical-scale timeframe for prehistory is emerging. This seems like a contradiction, but it is reality. Work on the British Neolithic led the way. We now know that this dramatic socioeconomic transformation began about 4050 BC, and we can map in detail the progressive spread of this new lifeway across England, Wales, Scotland, and Ireland within less than three centuries (Whittle et al. 2011). Our temporal horizons have been pushed back, from redefining the peopling of the Americas since the secure dating of Monte Verde in Chile at least 14,500–18,500 years ago

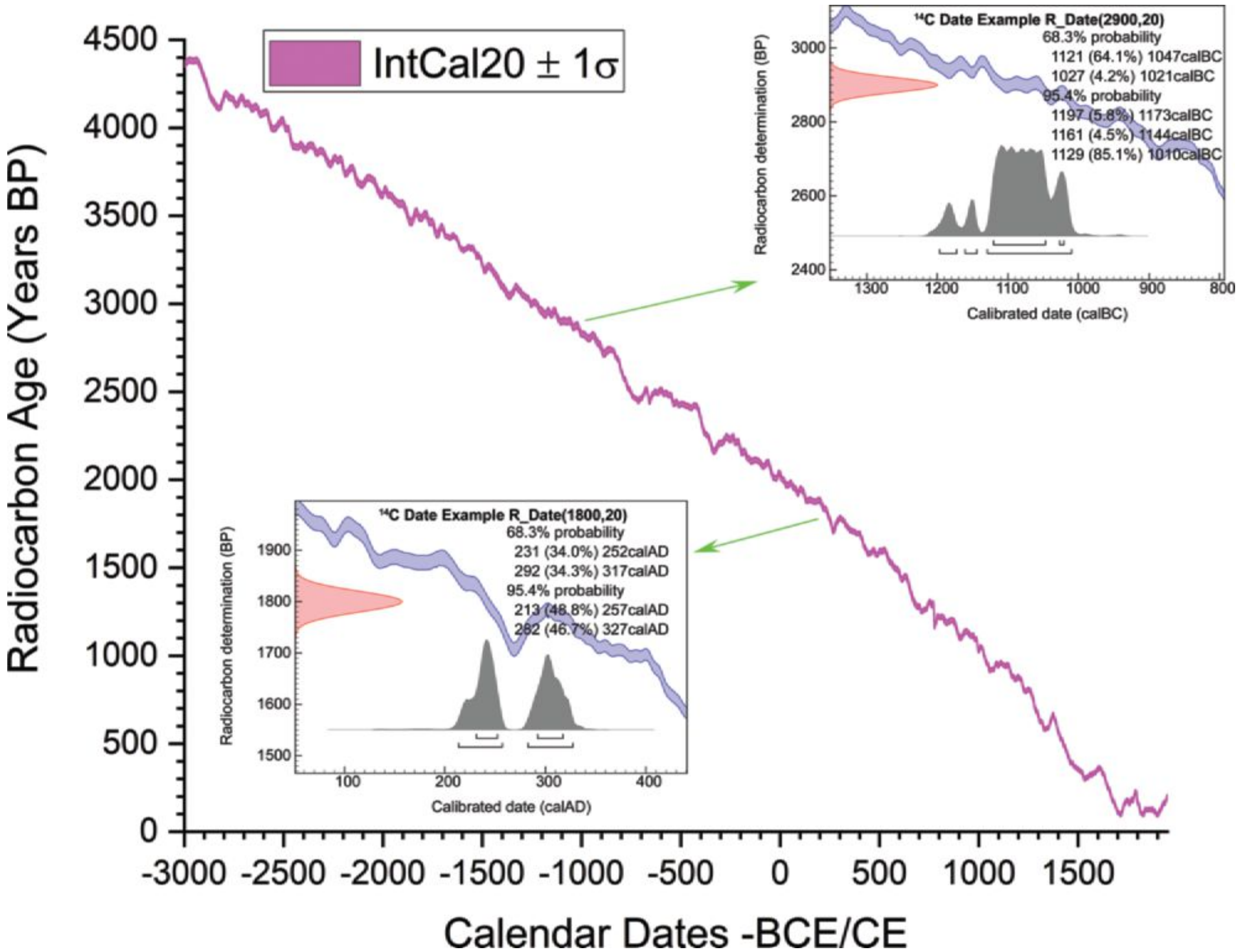

Figure 1. IntCal20 radiocarbon calibration curve AD 1950–3000 BC. IntCal20 covers AD 1950–53,051 BC (55,000 years ago from AD 1950). Two examples of calibration are shown for radiocarbon (^{14}C) dates of 2900 ± 20 BP and 1800 ± 20 BP (using OxCal). Note how the shape of the calibration curve (past variations in atmospheric radiocarbon concentration) determines the nature of the calibrated calendar age probabilities and range(s).

(Dillehay et al. 2015), to the ability to quantify better the replacement of Neanderthals by modern humans in Europe (Hublin et al. 2020). But, just as striking, this potential means that sophisticated radiocarbon analysis can actually refine and even challenge long established approximate chronologies built from partial historical information in the more recent periods. Two examples are the following. First, a 2010 project demonstrated that it could not only provide dates for Egyptian history but actually refine these and help decide between different historical reconstructions (Bronk Ramsey et al. 2010). Second, a project working on sites in southern Ontario was able to date the largest yet excavated Iroquoian settlement, Jean-Baptiste Lainé (or Mantle), to within a four-decade period at 95.4% probability, and was able to demonstrate that the previous dating based on semi-historical principles was incorrect by more than 50 years (Manning et al. 2018)—even though this was only just over 400 years ago.

Particularly in Europe, modern radiocarbon dating and Bayesian modeling are providing the timetable for a new human-lifetime-scale anthropological archaeology that is radically transforming the field. To gain a grasp of the scope of the possibilities and excitement, see Alasdair Whittle (2018).

Recognizing Opportunity, Enacting Potential

With precision comes challenge. Precision is not accuracy. Thus, the ability to date very small samples with AMS in fact brings up new issues. Confronted with a large lump of charcoal, problems of contamination can usually be avoided. The trouble is that one dates a large lump of charcoal, which might contain several to hundreds of tree rings and offer a date several to hundreds of years older than the find context—and that is assuming the lump includes the outermost ring (bark or waney edge); otherwise there is even more of an in-built age offset (the so-called old-wood effect). Thus, an accurate but relatively useless date. In reverse, we may date subannual growth plant remains from an archaeological context. Such samples, from food remains or stores, offer direct and specific dates. The question is then whether such samples relate specifically to the archaeological feature of interest. We require micro-stratigraphic detail and forensic focus. We need to know exactly what comprises the sample. The days of a "small piece of charcoal" as a sample must end. What is it, exactly? And how does it associate with the archaeological context of interest? Further, the smaller the sample, the more even minor contamination in fact becomes important. Thus, extreme care is necessary to ensure samples are excavated, recorded, identified, stored, processed, and dated without introducing any contamination. The expectation today is a set of dates for any given element or context to achieve a replicated and robust age estimate for a particular deposit.

However, radiocarbon dates by themselves, or even a set of dates on one sample or context, are often largely useless. With rare exceptions—during periods when over many decades radiocarbon levels were rapidly changing in one direction—a single date or set of dates will usually yield a large calendar age range, or even worse, multiple possible age ranges, when converted in calendar years via the radiocarbon calibration curve. And here recent progress in fact only makes the problem worse. The refined annual detail of the new IntCal20 calibration curve means more wiggles in the calibration curve and more possible dates and ambiguities. Thus, to gain chronological precision and accuracy, and to take advantage of the now very detailed calibration curve, it becomes essential to work with sets of dates with known relative structure or associations such that a solution, simultaneously, of multiple parameters will resolve a narrow possible range.

Possibilities and potentials vary according to the types of sites and occupational histories in different areas. Short-lived occupations, but perhaps as part of a community relocation sequence, provide one end of the spectrum, whereas multiphase mound sites offer the potential to pursue detailed internal stratigraphically defined sequences and to test relations between areas of larger settlements. Work is beginning, but there is great undeveloped potential. Just consider a site like Kincaid (Cole et al. 1951), which was central to the development of stratigraphic methods in the history of U.S. archaeology. Not only are there complex stratigraphic relationships, but the site also produced numerous tree-ring samples. Although the original attempts by Robert Bell to establish tree-ring dates were unsuccessful, these samples offer the potential for the application of a high-resolution form of radiocarbon dating referred to as "wiggle-matching" that will likely be critical in the Americas in coming years. What is wiggle-matching? The radiocarbon calibration curve is constructed of high-resolution measurements of tree rings for specific years or groups of years. Thus, for an undated tree-ring sample (whether as wood or charcoal)—for example, with 50 annual tree rings—if we were to radiocarbon date individual rings like 5, 15, 25, 35, and 45, or sets of rings like rings 3–7, 13–17, 23–27, 33–37, and 43–47, knowing that each sample (or the midpoint of groups of rings) is exactly 10 years apart, we can hope to place (i.e., wiggle-match) this series against the calibration curve to get a specific fit (Galimberti et al. 2004). With a longer series and several radiocarbon dates, the fit should be close; with a shorter sequence and a few dates, it is more approximate. This method offers a powerful alternative when direct dendrochronological dating—against secure tree-ring series—is not possible. For a recent example using wiggle-matching to date first-millennium AD archaeological samples in northwest Mexico, see Paula Turkon and colleagues (2018).

An Example of What Is Possible and Should Be Standard

A hypothetical example illustrates the potentials. The modeling depicted in Figure 2 uses OxCal 4.4.1 and the IntCal20 radiocarbon calibration curve. (A) Let us consider a site (assume a mound site). Excavations in an area reveal a stratigraphic sequence starting with an initial occupation (Layer IV) to a final occupation (Layer I). Within these main stratigraphic phases there could be sub-elements (e.g., multiple structures or episodes in Layers III and II). A burnt wooden post was retrieved from the primary construction of Layer II. The paleobotanist recognized bark (so a felling date) but said there were fewer than 50 tree rings present; thus, dendrochronology was unlikely to be able to date this sample, even if there was a suitable reference chronology for this species in this region. As a result, it was packed away in a box. (B) Four radiocarbon dates were obtained on short-lived plant matter (like burnt maize) from the paleobotanical assemblage gathered through excavation and flotation from each level (16 dates altogether). Radiocarbon dates on such short-lived material

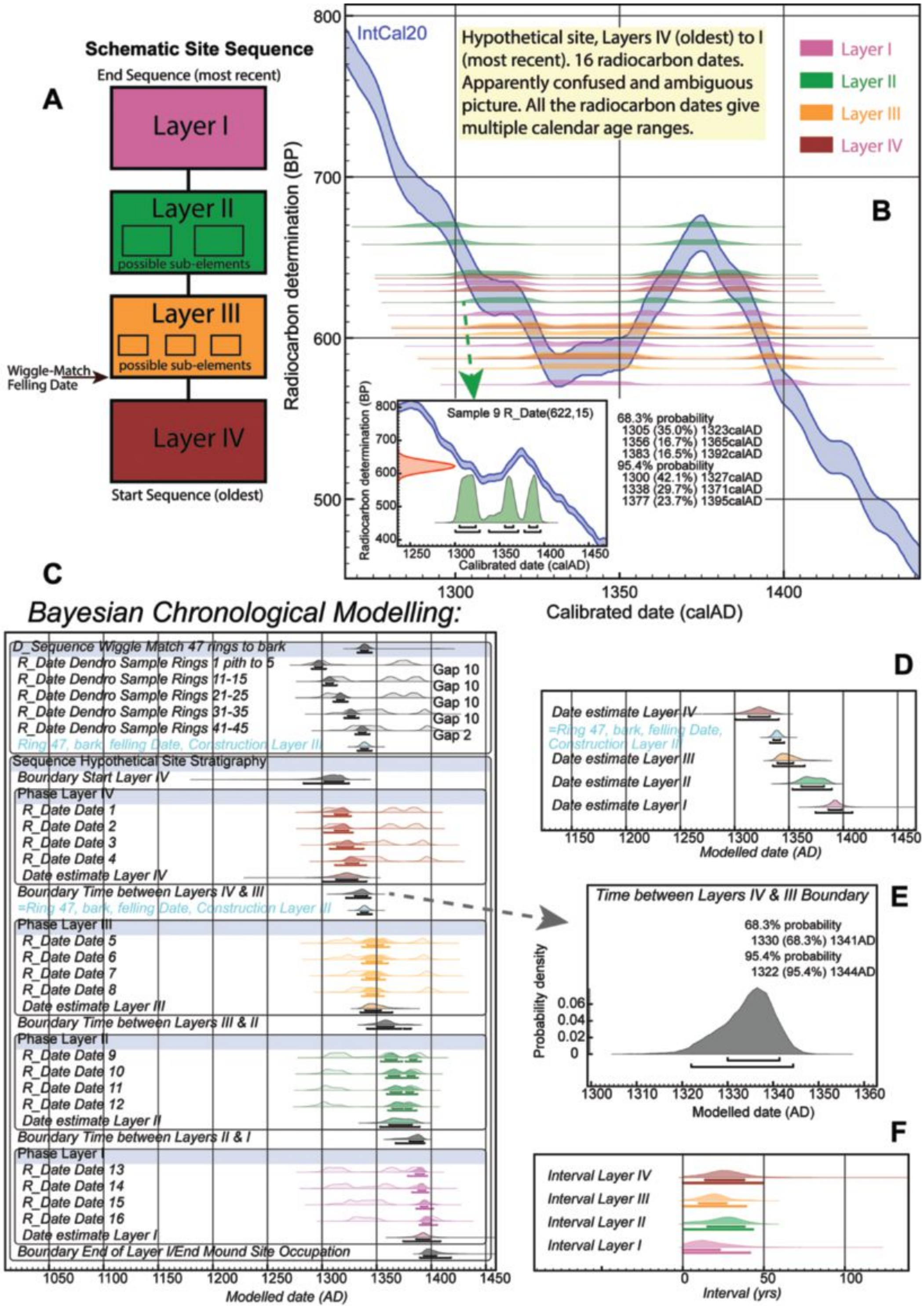

Figure 2. Bayesian chronological modeling of a hypothetical mound site and radiocarbon dates using IntCal20 and OxCal.

from secure contexts offer dates for the specific context of interest—and thus are the priority for dating efforts. But the radiocarbon dates when calibrated (compared to the IntCal20 calibration curve) offer multiple possible date ranges over a century or so, and the dates from Layers IV to I are all about the same (intermingled) and therefore ambiguous. (C) We have a stratigraphic sequence—prior knowledge. Someone also remembers there was that tree-ring sample. After contacting a tree-ring laboratory, the sample is identified (e.g., *Juniperus virginiana*), bark is confirmed, and a sequence of 47 rings identified. Although there are *Juniperus virginiana* chronologies, the sample (typically too short for reliable dendrochronology) does not offer any plausible cross date. Wiggle-match dating using the tree-ring sequence and radiocarbon is proposed. Five-year samples for rings 1–5, 11–15, . . . 41–45 are dissected and radiocarbon-dated for a wiggle-match to place the felling date, ring 47, which is also the start of Layer III occupation. Bayesian chronological modeling is carried out after building an OxCal model incorporating the stratigraphic sequence and the wiggle-match. The original calibrated date ranges are the light-colored histograms. The much smaller darker-colored histograms are the resultant modeled probability distributions given the constraints within the model. The lines under each indicate the most likely 68.3% and 95.4% ranges. There are now much more precise date ranges, and we see the stratigraphic order of the site represented. (D) The model includes some queries. For example, what is the probability for the date range between the start and end boundary for each phase—that is, the approximate date range for each of the layers? These can be quantified. (E) We can also quantify the time between the dated samples/events. Thus, the boundary between Layers IV and III can be calculated. This transition can be dated to a 22-calendar-year range at 95.4% probability. (F) Another query we can ask is the period of time (interval) between the start and the end boundary for each phase.

This type of analysis is now becoming standard (even unadventurous). Such approaches are not yet widespread in U.S. archaeology for all periods from the Pleistocene through to the earlier historic period but should be. A useful guide to Bayesian chronological modeling was published in *American Antiquity* two years ago (Hamilton and Krus 2018). An important aspect of such modeling is that the models can be tested for outliers and for whether they offer a plausible and robust result.

Northeast North America

The typically short-lived settlements of Woodland societies of the Northeast have proven challenging for radiocarbon dating in the past. The necessary precision was often lacking. Dating a site to a range of around, or often more than, 100 years was not really useful. Lots of sites might or might not be contemporary. The temporal resolution necessary to address patterns of social, economic, political, and ideological change was problematic. The application of all the recent advances in radiocarbon dating have changed the dating game. A refined calibration curve, modern AMS radiocarbon dates on short-lived plant samples—potentially even from earlier and later stages within a village occupation—and even potentially some short wiggle-matches, and Bayesian modeling all offer a new way to address chronology in this region with a resolution at the scale of a village lifespan or even less. The Dating Iroquoia project (https://datingiroquoia.wordpress.com/) is an example of new work exploiting these potentials. It also offers a useful opportunity to demonstrate that the methods are robust against a case where there is also historical information—thus, to show that the "science" works.

Let us consider the Ball and Warminster sites, both of which are ancestral Huron-Wendat villages in Ontario, Canada. Point #1: these two proximate sites are regarded as part of a community relocation sequence, with the order of Ball and then Warminster based on the material culture assemblages. Point #2: ethnohistoric sources, as well as archaeological investigation into building histories and environmental constraints, indicate that large villages of this type were occupied for only a few decades, typically around no more than 20–30 or so years, with an approximate upper limit of about 40 years; we may include this approximate expectation within the model; for example, stating we expect a settlement length comprising a Normal Distribution of mean 25 ± 10 years (so, range 5–45 years at 95.4% probability). Point #3: finally, we have a tree-ring series from a post recovered from Warminster—the last extant ring is not the original outer ring of the sample, so it probably sets a terminus post quem for the Warminster phase. In reverse, the presence of numerous European trade goods (glass beads) indicate approximate historical dates, and historical sources document that Samuel de Champlain visited this area and stayed at a village he called Cahiagué in AD 1615–1616 (and based on the account of a later French visitor, Gabriel Sagard, this was likely toward the end of the village's occupation period). Warminster has usually been considered the likely candidate for Cahiagué based on archaeological and linguistic arguments; Ball was about the only other possibility.

Thus, what does a Bayesian model find, incorporating prior knowledge of points #1, #2, and #3 above and the radiocarbon dates on short-lived plant material from the Ball and Warminster sites (for the data, see Manning et al. 2019)? See

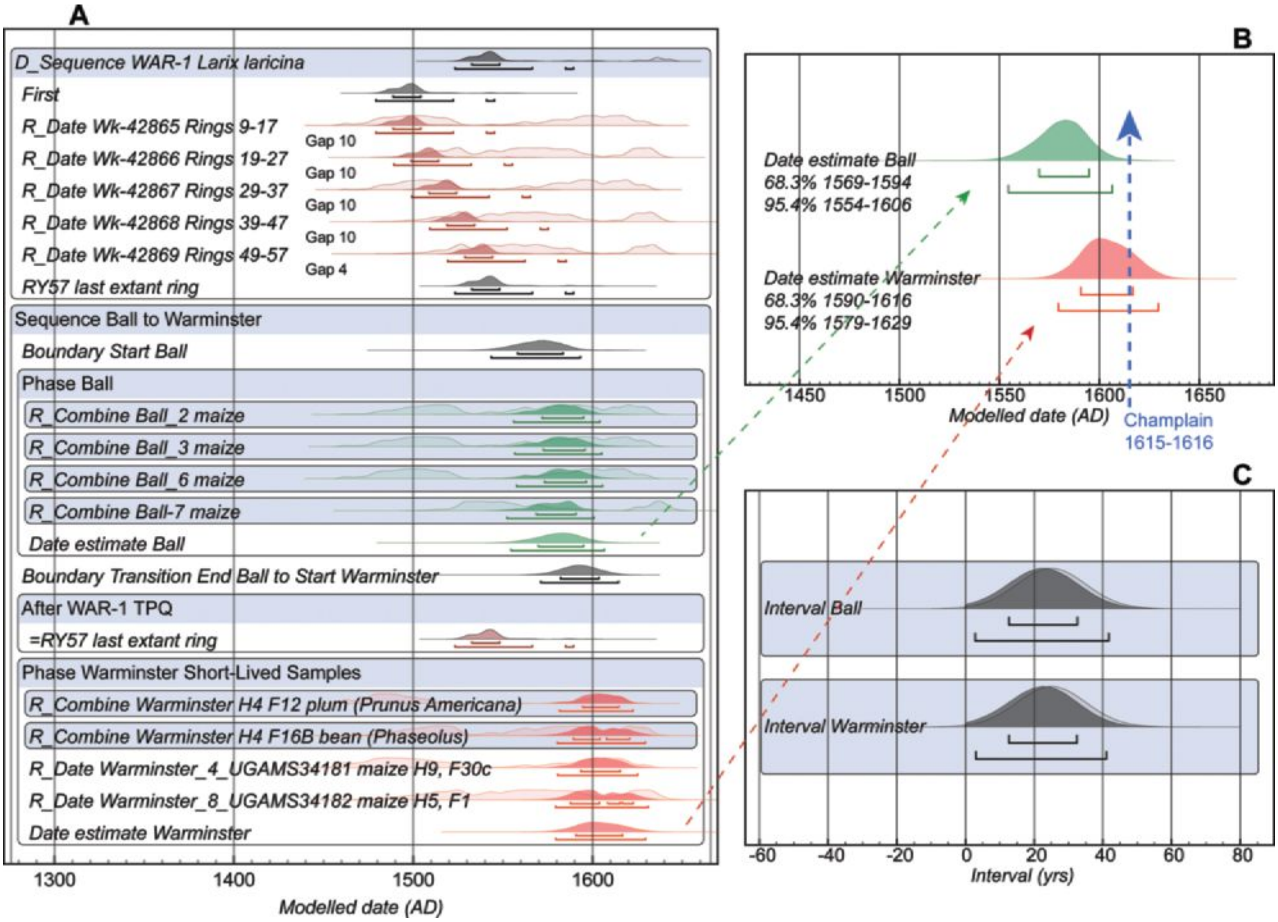

Figure 3. Bayesian chronological modeling of the Ball and Warminster site sequence (Ontario, Canada) using data from Manning and colleagues (2019).

Figure 3: (A) shows the dating model for the site integrating the radiocarbon data with the additional assumptions; (B) shows the date estimates (the period between the start and end boundaries for each site) for Ball and then Warminster. The date for Champlain's stay (winter 1615–1616) at Cahiagué, later in the lifetime of this village, is indicated and matches well with Warminster. (C) The modeled duration or lifespan of each village (solid histogram) versus the prior assumption (a Normal Distribution of 25 ± 10 years; hollow histogram)—there is a good concordance in each case, suggesting this was a reasonable assumption. Changing the prior assumption, for example to 20 ± 10 years, or to a different form of probability distribution like a log-normal distribution, would of course make small differences. As with all statistics, it is necessary to explain assumptions and to test whether data and assumptions are within a compatible range.

Did the model get the "correct" answer, or something close to "correct"? And what resolution was achieved? The example in Figure 3 shows that, yes, we can aim to resolve such site histories to a few decades of time and with historical-level accuracy. Where we do not have a rare historical record, like the Champlain-Cahiagué instance, we can nonetheless now use radiocarbon-based investigations to achieve near-historical temporal resolution. This means we can build timescales with the resolution to investigate the mosaic of social connections and changes and regional history, and issues like the relationships of societies with high-resolution climate records, all at the necessary fine-grained temporal scale of individual human lives and individual settlements. Previously hidden aspects of Woodland societies will be revealed. There is the potential now to write a new detailed history of the era of early European exploration and settlement of the Northeast, and to refine understandings of contact-era events. Modern radiocarbon dating and analysis is at the heart of a wave of high-resolution temporally driven work changing American archaeology.

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