

**A New Radiocarbon Sequence from Lamanai, Belize:  
Two Bayesian Models from One of Mesoamerica's Most Enduring Sites**

Accepted Manuscript, 5-June 2016  
Version of Record:  
<https://doi.org/10.1017/RDC.2016.44>

Jonathan A. Hanna  
Department of Anthropology  
Pennsylvania State University  
409 Carpenter Building  
University Park, PA 16802  
**Corresponding author:**  
jah1147@psu.edu

Elizabeth Graham  
Institute of Archaeology  
University College London  
31-34 Gordon Square  
London WC1H 0PY

David M. Pendergast  
Institute of Archaeology  
University College London  
31-34 Gordon Square  
London WC1H 0PY

Julie A. Hoggarth  
Department of Anthropology  
Baylor University  
One Bear Place #97173  
Waco, TX 76798

David L. Lentz  
Department of Biological Sciences  
University of Cincinnati  
614 Rieveschl Hall  
Cincinnati, OH 45221

Douglas J. Kennett  
Department of Anthropology  
Institutes of Energy and the Environment  
409 Carpenter Building  
Pennsylvania State University  
University Park, PA 16802

## 1 **Abstract:**

2 The ancient Maya community of Lamanai, Belize, is well-known for its span of occupation from  
3 the Early Preclassic (before 1630 BC) to the present. Although most centers in the central and  
4 southern Maya Lowlands were abandoned during the Terminal Classic period (AD 750-1000),  
5 ceramic and stratigraphic evidence at Lamanai has shown continuous occupation from the start  
6 of the Early Preclassic to the Spanish Conquest. In this paper, we present the first complete set of  
7 radiocarbon dates from this important site, including 19 new AMS <sup>14</sup>C dates. We use these dates  
8 to build Bayesian models for a Terminal Classic structure and an Early Postclassic structure in the  
9 site center. This method assists in the refinement of older, conventional dates and provides key  
10 chronological information about the site during this volatile time. Adjustments to the standard,  
11 uniform distribution model are made using exponential, long-tail, and trapezoidal distributions  
12 to incorporate outlier samples and more accurately portray ceramic phases. Because of changes in  
13 construction behavior in the Terminal Classic, it is difficult to acquire primary samples from this  
14 period, but there remains enough overlap between dates and ceramic phases to deduce persistent  
15 occupation at Lamanai during the transition from Late Classic to Postclassic times.

16

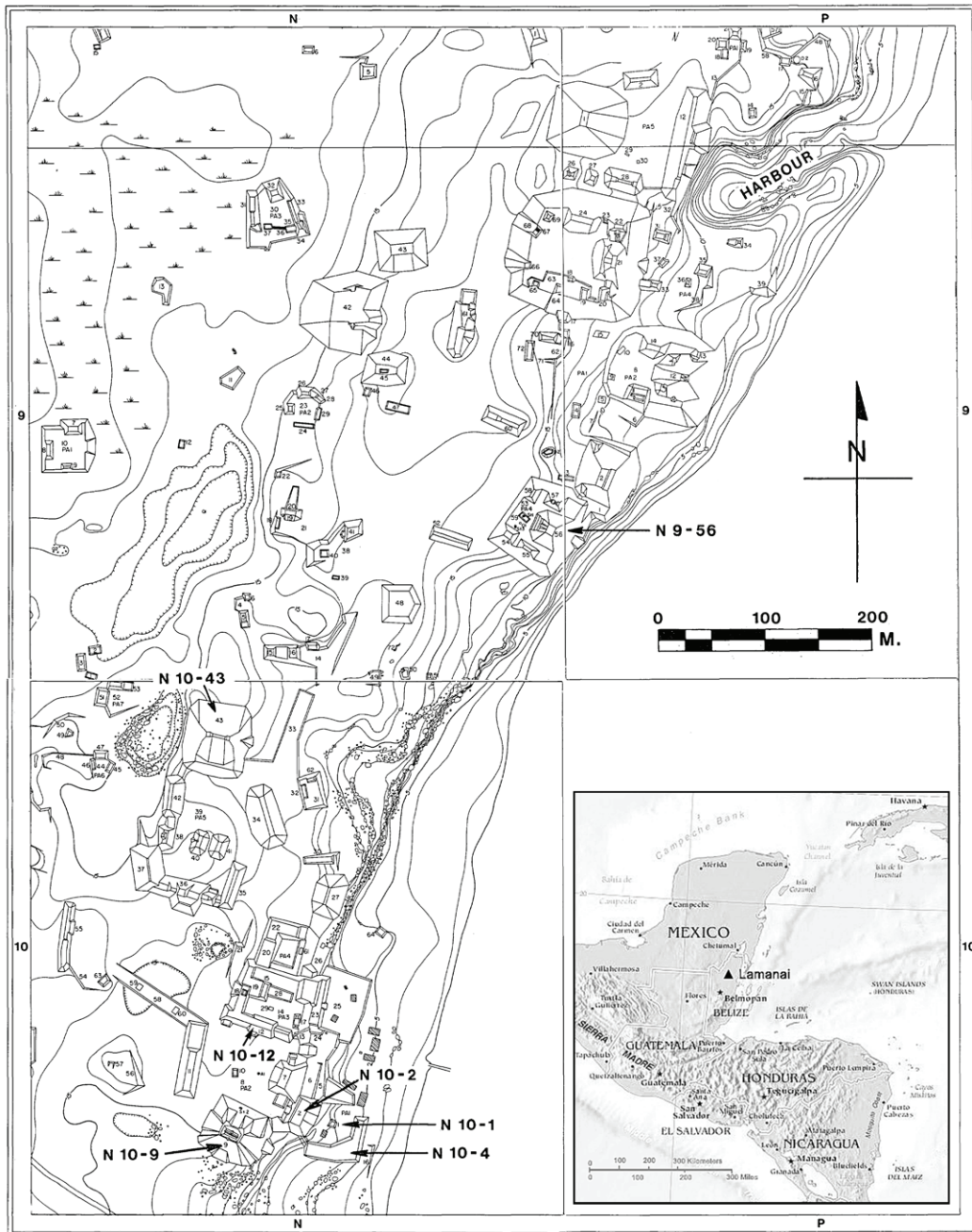
## 17 **Introduction**

18 The ancient city of Lamanai boasts one of the longer chronologies known for any Maya site.  
19 Ceramic and architectural evidence support occupation extending from the Early Preclassic (1600-  
20 900 BC) (Metcalf et al. 2009; Rushton, Metcalfe, and Whitney 2013) through the Spanish and  
21 British colonial periods and into the 21<sup>st</sup> century (Pendergast 1981; Pendergast 1982a; Graham  
22 1987; Pendergast 1988; Powis 2002; Graham 2004; Graham 2011). Like other ancient cities in  
23 the Maya Lowlands, Lamanai experienced profound changes during the Terminal Classic period  
24 (AD 750-960),<sup>1</sup> including diminution in monumental construction, increased use of wood as a  
25 construction medium for civic buildings, and changes in portable material culture. By the time  
26 of the Spanish Conquest, the community's center was positioned far south of the former Classic-  
27 period core, and the monumental structures built during the Classic (AD 250-1000) were no longer  
28 in use (Pendergast 1981; Pendergast 1998), although some plaza groups were reoccupied during  
29 the Colonial period (Graham 2011). Pendergast (1986) attributes Lamanai's perseverance in part  
30 to its location along the New River Lagoon— a rich, freshwater resource that provided a means of  
31 subsistence, transportation, communication, and trade with other regions of Mesoamerica. Recent  
32 paleolimnological studies (Metcalf et al. 2009; Rushton, Metcalfe, and Whitney 2013) confirm the  
33 lagoon's reliability and resilience to the prehistoric climatic fluctuations that affected other parts of  
34 the Maya Lowlands (Haug et al. 2001; Hodell, Brenner, and Curtis 2005; Mueller et al. 2010; Aimers  
35 and Hodell 2011; Kennett et al. 2012; Douglas et al. 2015).

36

37 Lamanai consists of 718 structures positioned along a 4.5 sq. km section of the New River Lagoon  
38 in northern Belize (Figure 1) (Pendergast 1981:32). Preclassic settlement was largely concentrated  
39 in the north with the location of the community's core expanding southward over time. Preclassic  
40 activity appears to have been extensive— in fact, the Spanish churches far to the south of the site  
41 core were constructed in a zone of Preclassic occupation. Recent pollen analysis has confirmed  
42 Early Preclassic activity with the presence of *Zea mays* and *Cucurbita sp.* beginning by 1630 BC  
43 (Metcalf et al. 2009; Rushton, Metcalfe, and Whitney 2013), and a maize offertory deposit in the  
44 northern “harbor” area has been dated to 1500 BC (Pendergast 1998:56; Powis, Mazzullo, and  
45 Graham 2009). Although many of the northernmost structures had fallen into disuse by the

1 beginning of the Classic period, occasional venerations continued, as represented by deposits of  
 2 ceramics from later periods at the base of some temples (Pendergast 1981). Additionally, nearly 100  
 3 ceramic censers were ritually smashed atop the degraded surface of the Mask Temple (Structure  
 4 N9-56) during the Late Postclassic (AD 1350-1544), accompanied by a re-sitting of Stelae 1 and 3  
 5 (Pendergast 1981:51; Pendergast 1986:240). Such ceremonies were typical of the Late Postclassic  
 6 Lowlands, yet the venerations at Lamanai were more substantial than the portable offerings found  
 7 at abandoned centers elsewhere (Pendergast 1985:99; Hammond and Bobo 1994; Sullivan and  
 8 Sagebiel 2003).  
 9



1 The first systematic archaeological investigations at Lamanai were carried out from 1974 to 1986  
2 and consisted of mapping, excavation, and consolidation (Pendergast 1981; 1982a,b; 1985; 1986;  
3 1988; 1990; 1998; 2006). Since 1998, excavations have concentrated on periods of cultural transition,  
4 focusing particularly on the Terminal Classic, the Spanish Colonial period, and more recently,  
5 British colonial activities (Graham 2004, 2008, 2011; Mayfield 2015).

6

### 7 **The Sampling Contexts: Structures N10-2, N10-7, and N10-9**

8 The southern end of Lamanai's Central Precinct consists of a series of interconnected plazas, the  
9 largest of which, Plaza N10[2], is dominated by the Jaguar Temple (Str. N10-9 on Figure 1). Most  
10 of the investigated structures in the site core were constructed during the Late Preclassic (400-100  
11 BC) and underwent numerous modifications later in their history (Pendergast 1981; Loten 2006).  
12 The Jaguar Temple is one of the few large structures to have been erected during the Early Classic  
13 (AD 250-450) (Pendergast 1981:35).

14

15 In the shadow of the Jaguar Temple, bordering the lagoon to the east, a small plaza-like complex  
16 appears to have been the focus of activity from Terminal Classic through Late Postclassic times.  
17 Structure N10-2, which featured a distinctive columned portico with a masonry altar along the  
18 center of the back wall, is believed to have been built during the Terminal Classic and repeatedly  
19 renovated until the early 15th century (Pendergast 1986:241). Fifty burials were found in Str.  
20 N10-2, of which 25 were associated with diagnostic Buk phase ceramics (Early Postclassic pottery  
21 characterized by Zakpah Group vessels) (Walker 1990; Wrobel and Graham 2015).<sup>2</sup> Buk phase  
22 ceramics were also found in 20 of the 47 burials from Str. N10-4 of the same plaza, and in both  
23 burials from the small platform, N10-1, that lay between N10-2 and N10-4. Many of these burials  
24 contained prestige goods indicating high status, including copper ornaments, rings, and bells  
25 (Pendergast 1981; Pendergast 1985; Simmons, Pendergast, and Graham 2009).

26

27 The wealth of the Buk burial assemblages in Structures N10-1, N10-2, and N10-4 demonstrates  
28 that Lamanai remained an active and influential community during the Early Postclassic (AD  
29 900/960-1200) (Pendergast 1981:41). The site's importance during this period is also indicated by  
30 the presence of Zakpah ceramic types at Altun Ha, Mayflower, Tipu, and Marco Gonzalez (Graham  
31 1987), as well as at neighboring sites in northern Belize (Andres and Pyburn 2004; Wrobel and  
32 Graham 2015). Marco Gonzalez, on Ambergris Caye, appears to have been a thriving coastal trade  
33 port in the Early Postclassic (Graham, Pendergast, and Jones 1989; Pendergast 1990; Guderjan and  
34 Garber 1995), and the large quantity of Zakpah ceramics recovered there points to connections  
35 with Lamanai and other sites in northern Belize (Ting 2013).

36

37 Masses of Postclassic ceramic imports recovered on the lagoon shoreline east and south of Structure  
38 N10-4 may reflect greater involvement in commerce during the Postclassic period (Pendergast  
39 1985:98; Graham 2004:228; Powis, Mazzullo, and Graham 2009:259). Some of the structures from  
40 this time appear to face the lagoon, and farther south, several residential buildings (N11-5, N11-  
41 7, and N11-9) were constructed along the waterside during the Terminal Classic and Postclassic  
42 periods (Howie 2012:24), further supporting the strong connection of Lamanai's residents to  
43 coastal trade routes during the period (e.g., Chapman 1957; Sabloff and Rathje 1975; McKillop  
44 1996; Masson 2002; Masson and Freidel 2012; Masson and Freidel 2013; King 2015).

45

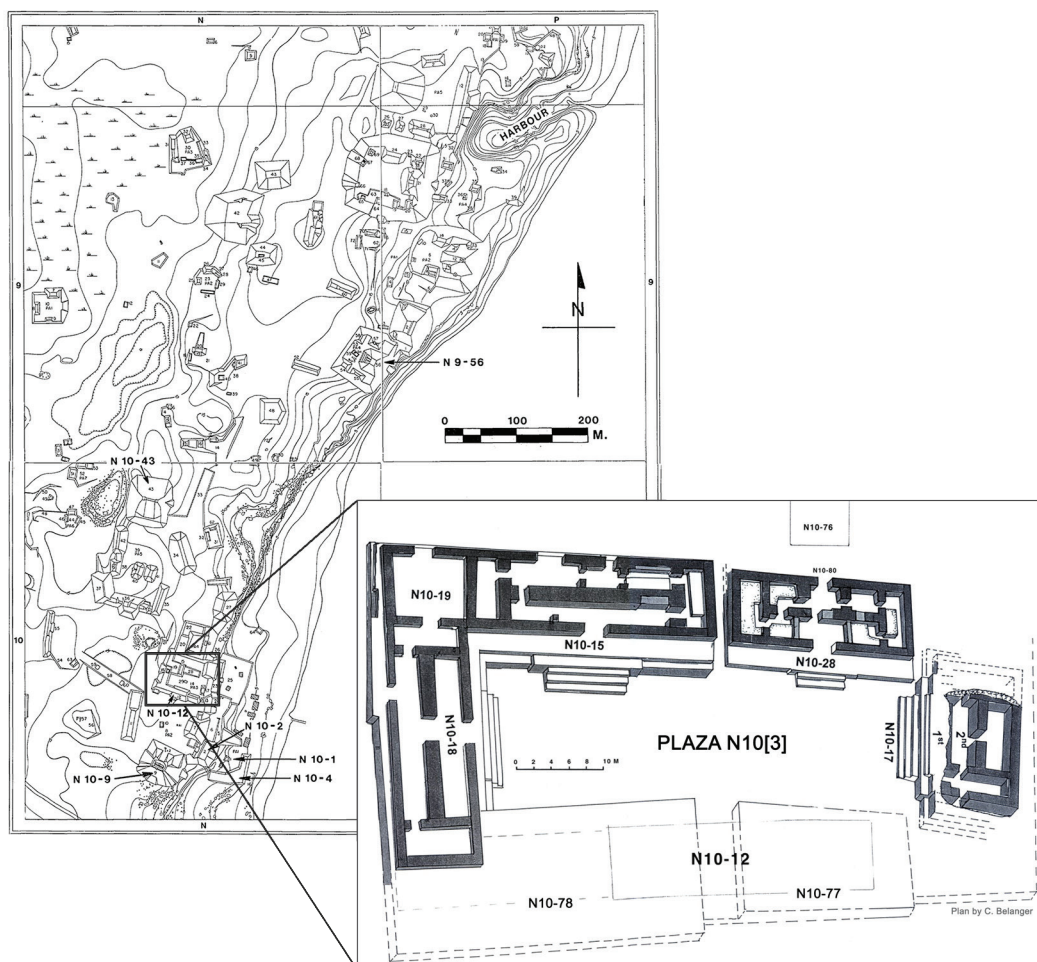


1 In 1976, 15 samples (13 wood charcoal fragments, one charred bean sample, and one charred  
2 maize sample) from Structures N10-2, N10-7, and N10-9 produced a series of uncorrected dates<sup>3</sup>  
3 that spanned the Classic and Postclassic periods.<sup>4</sup> The samples from primary contexts within Str.  
4 N10-2 (GX-4660, 4661, 4663, 4670) suggested that Postclassic ceramic trends (represented by Buk/  
5 Zakpah Group ceramics) were well developed by A.D. 1140 (Pendergast 1981:49–50). Reanalysis of  
6 these dates below indicates an even earlier appearance for this phase.

7

### 8 **The Sampling Contexts: Plaza N10[3], the Ottawa Group**

9 To the west of N10-4, two structures (Strs. N10-12 and N10-77) from Plaza N10[3] (Figure 2)  
10 provide a second set of radiocarbon dates from ongoing excavations since 1998 (Graham 2004;  
11 Graham 2007). Nicknamed the “Ottawa Group” by Canadian students working with H. Stanley  
12 Loten in 1975, Plaza N10[3] lies just north of the Jaguar Temple (N10-9). The range structures  
13 that were exposed through excavation in 1981 and 1982 (Pendergast 1982b; Pendergast 1985;  
14 Pendergast 2006:66)— Strs. N10-15, N10-28, N10-17, N10-18 on the north, east, and west sides  
15 of the plaza, respectively— showed Late Classic (AD 625-750) and Terminal Classic (AD 750-960)  
16 activity, with a large number of cached ceramics recovered from excavations in those structures.  
17 Burials that cut through the collapse of these buildings contained Buk phase vessels, originally  
18 dated by Pendergast to the Middle Postclassic (AD 1200-1350). The plaza area itself was cleared  
19 only far enough to expose the stairs of the excavated structures; its full extent was not uncovered



1 until work in 2002 and 2003.

2

3 Beginning in 1998, new excavations at the Ottawa Group have revealed that the last standing  
4 masonry architecture around Plaza N10[3] date to the transition from the Late Classic to Terminal  
5 Classic periods. Towards the end of the 8<sup>th</sup> century, the masonry buildings were razed (except  
6 for Strs. N10-15 and N10-18) and the entire courtyard filled with 2.5m (21,000 metric tons) of  
7 large, quarried blocks, sascab (eroded limestone bedrock), and Terminal Classic midden (dubbed  
8 the “Boulders” phase), and then capped with plaster. Excavations in 2002-2003 identified that  
9 the southern structure of the courtyard, Str. N10-77, was covered by a low masonry platform  
10 that supported a wooden superstructure (Str. N10-12) dating to the Terminal Classic and Early  
11 Postclassic periods. Buk phase burials within the Boulder core were thus found to be associated  
12 with this perishable building (Graham 2004:235). Wooden buildings were also built atop N10-17  
13 and N10-28. Masonry additions and alterations continued to be made to N10-15 and N10-18, but  
14 ultimately these, too, were razed, and wooden structures on low stone platforms were built atop  
15 what remained. As a result of these investigations, the timing of the Buk phase was subsequently  
16 realigned from the Middle Postclassic period (AD 1200-1350) (Graham 1987; Pendergast 1981) to  
17 the Early Postclassic period (AD 900/960-1200) (Graham 2004).

18

## 19 **Methods**

20 During the 2002-2003 field seasons, excavations in 15 contexts from N10-77 and N10-12 yielded 17  
21 wood charcoal samples: 12 from secure primary deposits (11 caches and one burnt stratum), and  
22 three from less secure, secondary contexts (one from a midden used in a bench extension; one from  
23 the core of a bench; and one sample from a concentration of Zakpah sherds in the Boulder core).  
24 Identification of botanical materials was conducted at the Paleoethnobotanical Laboratory at the  
25 University of Cincinnati, after which the samples were sent to the Oxford Radiocarbon Accelerator  
26 Unit (ORAU) for AMS <sup>14</sup>C analysis in 2007.

27

28 At ORAU, the samples first underwent standard ABA pretreatment to remove intrusive sediments  
29 and contaminants (Brock et al. 2010, Staff et al. 2014). The wood was shaved (20-100 mg) with a  
30 scalpel, and then soaked in 1M HCl for 20 minutes. The sample was then rinsed in ultrapure water  
31 before undergoing repeated 20 minute soakings in 0.2M NaOH until the solution was colorless.  
32 The samples were again washed in ultrapure water and subjected to the final ABA stage of soaking  
33 for 60 mins in 1M HCl. Wood samples are then typically soaked in a 5% bleach solution for no  
34 more than 30 mins, to break down resins, waxes, and lignin. It is then freeze-dried so as to provide  
35 optimal conditions for combustion and graphitization. Dried samples were loaded into tin capsules,  
36 combusted, and converted into N<sub>2</sub> and CO<sub>2</sub>. The CO<sub>2</sub> was graphitized using methods laid out in  
37 Dee and Bronk Ramsey (2000). Finally, the samples were measured in ORAU's HVEE tandem AMS  
38 system, online since 2002.

39

40 In addition to the 17 AMS <sup>14</sup>C dates from the Ottawa complex, three contexts from N10-2, originally  
41 dated in 1976, were re-analyzed at ORAU (contexts LA 115/1C, LA 34/1C, and 34/2C). One of  
42 these new samples (34/2C) did not produce a carbon yield and was subsequently rejected for AMS  
43 <sup>14</sup>C re-dating.<sup>5</sup>

44

45 For the present paper, all samples were recalibrated using OxCal version 4.2.4 (Bronk Ramsey

1 2009b; Bronk Ramsey 2014a) and 100% of the IntCal13 northern hemisphere curve (Reimer et al.  
2 2013). Of the 15 contexts from N10-77 and N10-12 that produced samples, two (LA 1777 and LA  
3 1894) contained two samples each (hence 17 total samples from these structures). These 17 samples,  
4 plus the two successfully re-analyzed from 1977 are presented in Table 1 and detailed in Appendix  
5 I, along with the other 15 radiocarbon dates mentioned above, run by Geochron Laboratories in  
6 1977. Appendix I also includes the remaining set of available dates from Lamanai that were not  
7 used in a modeled sequence below, including those from N10-9 (the Jaguar Temple), N10-27 (the

Lab # (Sample #)	Lot #	Structure	$\delta^{13}\text{C}$	Corrected Radiocarbon Age (BP), $1\sigma$	calAD (IntCal-13), $2\sigma$	
					range	P
GX-4659	LA 30/1C	N10-2	-24 <sup>^</sup>	1786 ± 139*	90BC-AD565	95.40%
GX-4660	LA 34/1C	N10-2	-17.4*	915 ± 115	710-1225	95.40%
GX-4661	LA 34/2C	N10-2	-25.6*	830 ± 120	975-1395	95.40%
GX-4662	LA 110/1C	N10-2	-25.3*	1235 ± 130	550-1035	95.40%
GX-4663	LA 115/1C	N10-2	-27.7*	715 ± 130	1035-1435	95.40%
GX-4664	LA 115/2C	N10-2	-24 <sup>^</sup>	1251 ± 129*	545-1025	95.40%
GX-4665	LA 136/1C	N10-2	-26.2*	1690 ± 125	55-600	95.40%
GX-4666	LA 139/1C	N10-2	-24 <sup>^</sup>	826 ± 134*	905-1410	95.40%
GX-4667	LA 166	N10-7	-24 <sup>^</sup>	1526 ± 134*	215-770	95.40%
GX-4668	LA 167/1C	N10-2	-24 <sup>^</sup>	926 ± 129*	775-1385	95.40%
GX-4669	LA 171/1C	N10-2	-24 <sup>^</sup>	1191 ± 129*	605-1150	95.40%
GX-4670	LA 177/1C	N10-2	-24 <sup>^</sup>	1061 ± 124*	685-1215	95.40%
GX-4671	LA 207	N10-9	-24 <sup>^</sup>	1611 ± 134*	125-660	95.40%
GX-4672	LA 208	N10-9	-24 <sup>^</sup>	1511 ± 134*	215-775	95.40%
GX-4673	LA 209	N10-9	-24 <sup>^</sup>	1401 ± 188*	240-1020	95.40%
OxA-17968 (1)	LA 1742	N10-12	-25.9	1050 ± 24	900-925 960-1025	5.00% 90.40%
OxA-17969 (2)	LA 1764	N10-77	-26.8	1312 ± 25	655-725 740-770	70.40% 25.00%
OxA-17970 (3)	LA 1777	N10-77	-25.7	1409 ± 25	600-665	95.40%
OxA-17971 (4)	LA 1778	N10-77	-25.3	1423 ± 25	585-660	95.40%
OxA-17972 (5)	LA 1779	N10-77	-26.3	1367 ± 26	615-685	95.40%
OxA-17973 (6)	LA 1783	N10-77	-26.1	1280 ± 24	670-770	95.40%
OxA-17974 (7)	LA 1784	N10-77	-26.1	1304 ± 25	660-725 735-770	65.90% 29.50%
OxA-17975 (8)	LA 1785/1	N10-77	-26.7	1297 ± 25	660-730 735-770	63.10% 32.30%
OxA-17976 (9)	LA 1798	N10-77	-26.1	1284 ± 25	665-770	95.40%
OxA-17985 (3)	LA 1777	N10-77	-26.6	1402 ± 25	600-665	95.40%
OxA-18014 (10)	LA 1894/6	N10-12	-26.3	1282 ± 26	665-770	95.40%
OxA-18015 (11)	LA 1894/8	N10-12	-26	1206 ± 26	715-745 765-890	6.10% 89.30%
OxA-18016 (12)	LA 2522	N10-77	-26.2	1260 ± 26	665-780 790-805 810-825 840-865	90.50% 1.70% 0.90% 2.30%
OxA-18017 (13)	LA 2524	N10-77	-26.1	1275 ± 26	670-775	95.40%
OxA-18018 (14)	LA 2525	N10-77	-26.1	1331 ± 27	645-715 740-765	81.40% 14.00%
OxA-18019 (14)	LA 2525	N10-77	-26.1	1282 ± 26	665-770	95.40%
OxA-18020 (15)	LA 2532	N10-77	-28.3	1240 ± 26	685-780 785-875	64.50% 30.90%
OxA-18021 (16)	LA 34/1C	N10-2	-9.62	856 ± 25	1055-1255	95.40%
OxA-18022 (18)	LA 115/1C	N10-2	-26.2	950 ± 25	1020-1155	95.40%

Calibrated with OxCal v4.2.4 (Bronk Ramsey 2013)

IntCal13 northern atmospheric curve (Reimer et al. 2013); all calibrations rounded to 5

\*Estimated, based on Stuiver and Reimer 2015, see text and Table S3

<sup>^</sup>Based on Stuiver and Polach 1977

1 only structure associated with a hieroglyphic date), and N10-77. A total of 34 dates are presented in  
2 these tables, comprising the complete list of radiocarbon samples available from Lamanai to date,  
3 excluding the core samples taken in the New River Lagoon by Metcalfe et al. (2009) and the original  
4 1500 BC date from the Harbor area (Pendergast 1998).

5

#### 6 **Evaluation of the 1976-77 Geochron Dates**

7 The first set of samples from Lamanai were analyzed by Geochron Laboratories, Inc. (Cambridge,  
8 MA) in December 1976 through February 1977. By 1976, most radiocarbon labs in the US had  
9 adhered to the conventions laid out in the roughly ten major radiocarbon conferences since  
10 1954 (see list in Taylor and Bar-Yosef 2014:305). Still, it was not until Stuiver and Polach's (1977)  
11 publication that all labs began following the same standard practices. Even though these standards  
12 were presented at the July 1976 international conference in San Diego and Los Angeles, it is  
13 possible that some were not yet in place when the Lamanai samples were run at Geochron. Thus,  
14 before incorporating these dates in our analysis, we needed to assess the exact procedures used by  
15 Geochron at the time the samples were run in 1976 (see the supplemental data in Kennett et al.  
16 2013 for another example of evaluating conventional radiometric dates; also Kennett et al. 2014).

17

18 According to laboratory announcements made in the journal *Radiocarbon* (Krueger and Weeks  
19 1965, 1966), Geochron began radiocarbon analysis in 1964, using the gas proportional counter  
20 technique (CO<sub>2</sub> method). At this time, pretreatment of wood samples included hot dilute HCl  
21 to remove carbonates, hot 2N NaOH to remove humic acids, and "thorough rinsing" (Krueger  
22 and Weeks 1965:47). Libby's revised half-life (5568 ± 30) was used, as is still the convention today  
23 (Godwin 1962). Oxalic Acid was used as the standard for modern activity (Olsson 1970), though  
24 the oxalic acid reference was likely the original 1957 NBS mixture rather than the "new" batch  
25 produced in 1977 (Taylor and Bar-Yosef 2014:122). Because the "new" batch contained slightly  
26 more activity than the original, using the original standard would actually have improved the  
27 quality of the measurement (though the error ranges were so wide at this time as to make the  
28 improvement negligible). The reference year used was 1950, as was required for all dates published  
29 in *Radiocarbon* after 1962 (Flint and Deevey 1962). However, it was not until Stuiver and Polach  
30 (1977) that  $\delta^{13}\text{C}$  corrections were required in reporting, though many researchers continued to  
31 report "uncorrected" dates thereafter (meaning the  $\delta^{13}\text{C}$  fractionation effects were not normalized).  
32 No reports of dates from Geochron during this decade contain  $^{14}\text{C}/^{12}\text{C}$  ratios or  $\delta^{13}\text{C}$  corrections  
33 (e.g., Honea 1975; Phillipson 1977; Nelson 1980).

34

35 For the Lamanai samples, Geochron initially reported only the "uncorrected" dates, but corrections  
36 for five samples were eventually sent in a later report. Unfortunately, while Geochron is still in  
37 business (now with an AMS service), they no longer possess records going back to 1976, so we  
38 cannot obtain the original report to see if any other  $\delta^{13}\text{C}$  values were taken. Instead, we used Stuiver  
39 and Polach's table (1977:358) to estimate the  $\delta^{13}\text{C}$  values for the remaining samples and then input  
40 those into a fractionation spreadsheet provided on the CALIB website (Stuiver and Reimer 2015)  
41 (see Table S3 of the Supplemental Materials). As described above, the corrected dates were then  
42 calibrated using the IntCal13 northern hemisphere curve (Table 1 and Appendix I).

43

#### 44 **Modeling**

45 The quality and quantity of the available radiocarbon samples allowed two Bayesian models to be



1 constructed for structures N10-2 and N10-77/N10-12 using the OxCal v.4.2.4 software package  
2 (Bronk Ramsey 2014a). OxCal uses a Markov Chain Monte Carlo (MCMC) sampler to approximate  
3 all possible solutions and probability outcomes (Bronk Ramsey 2008; Bronk Ramsey 2009b).<sup>6</sup>  
4 Bayesian statistics allow archaeologists to incorporate “prior” information about the samples into  
5 the statistical model, including relative stratigraphic and architectural sequences, monument dates,  
6 textual dates, ceramic chronologies, and unknown gaps between samples (Bronk Ramsey 2009b;  
7 Kennett et al. 2011; Culleton, Prufer, and Kennett 2012; Inomata et al. 2013; Hoggarth et al. 2014;  
8 Inomata et al. 2014; Kennett et al. 2014; Overholtzer 2014; Huster and Smith 2015; Ebert et al.  
9 2016). The relative ordering of samples within the stratigraphy of an excavation can therefore verify  
10 and constrain the calibrated date ranges. Given such influence, the prior knowledge must be robust,  
11 ideally from uncompromised, primary contexts with known associations to ceramic, architectural,  
12 or other chronologies (Pendergast 2000; Bronk Ramsey 2009b).

13

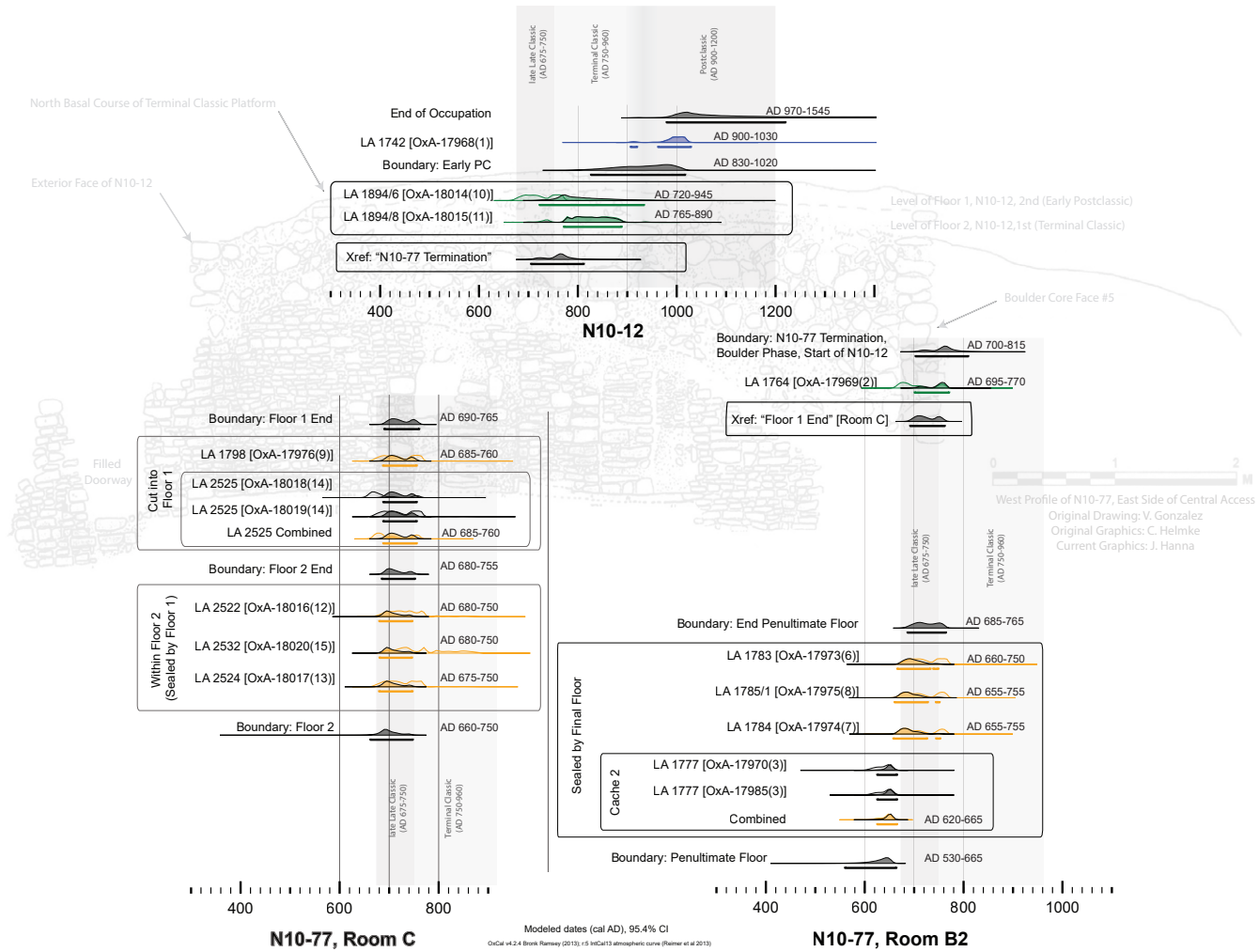
14 In some cases, the statistical model is able to identify incongruent (outlier) date ranges, allowing the  
15 researcher to investigate why certain samples may be problematic. In OxCal, this is indicated by the  
16 Agreement Index, which has a scale of roughly 0-100% and a cut-off at 60%, correlated to the 5%  
17 confidence interval of a chi-square test (Bronk Ramsey 1995; Bronk Ramsey 2009b). This indicates  
18 the agreement between a sample’s prior value and its posterior value from the model. Despite its  
19 usefulness, high agreement indices only show that the probability ranges are compatible— it is  
20 up to the researcher to decide, based on all available evidence, whether the agreement is actually  
21 significant. Graphically, the effects of model constraints can be seen in the generated histograms  
22 (Figures 3 and 5), where the original, unmodeled ranges are grayed in the background and the  
23 newly constrained (posterior) ranges are darkened in the foreground.

24

25 Even within pristine deposits, samples taken from the same context often cannot be placed in  
26 sequential order (e.g., multiple vessels in the same cache). Because the group as a whole precedes or  
27 succeeds other groupings, a *phase* designation in OxCal can be used as a container for an unordered  
28 group of dates within an otherwise ordered sequence. Similarly, the use of a *boundary* provides  
29 margins for an unknown span of time between two samples or phases (Bronk Ramsey 2000).

30

31 Because Bayesian models are the products of multiple lines of evidence, it can be difficult to use  
32 modeled data in subsequent radiocarbon sequences without including all of the prior information.  
33 For example, in the case of N10-77, two rooms with separate sequences were situated below structure  
34 N10-12, with the thick Boulder layer between them (Figure 3). This means that the N10-12 dates  
35 must be *later* than both N10-77 rooms, while the rooms themselves are independent sequences. In  
36 order to include all three sequences within the same OxCal plot, an *After* command (or *terminus*  
37 *post quem*) (Bronk Ramsey 2014b) was used, along with an *xref* parameter to cross-reference the  
38 end dates in each sequence. Likewise, provenience LA 1764 was from a burnt stratum in Room B2  
39 but represented the final termination event of Str. N10-77, which thus had to come *after* the last  
40 cache of the adjacent room (Floor 1, Room C). Since there is an unknown span of time between  
41 the Floor 1 cache and termination event, the *boundary* for the end of Floor 1 was cross-referenced  
42 instead of the latest sample from Floor 1. Similarly, a *terminus ante quem* of AD 1544 was used at  
43 the end of each model as a final constraint for the year Spanish encomiendas were established at  
44 Tipu and Lamanai (Graham 2011:49). These parameters can be seen in Figure 3 and in the OxCal  
45 codes listed in Table S2 of the Supplemental Materials.



1

## 2 **Sum and Trapezoidal Probabilities**

3 In addition to Bayesian modeling, all available dates were also evaluated using the OxCal *sum* and  
4 trapezoidal boundary models (Figure 4). Summed probability distributions essentially function  
5 the same as *phase* designations except that one histogram is generated for all samples within the  
6 sequence (Bronk Ramsey 2014b). A sum plot was generated for all dates studied in this project and  
7 is shown grayed in the background of Figure 4.

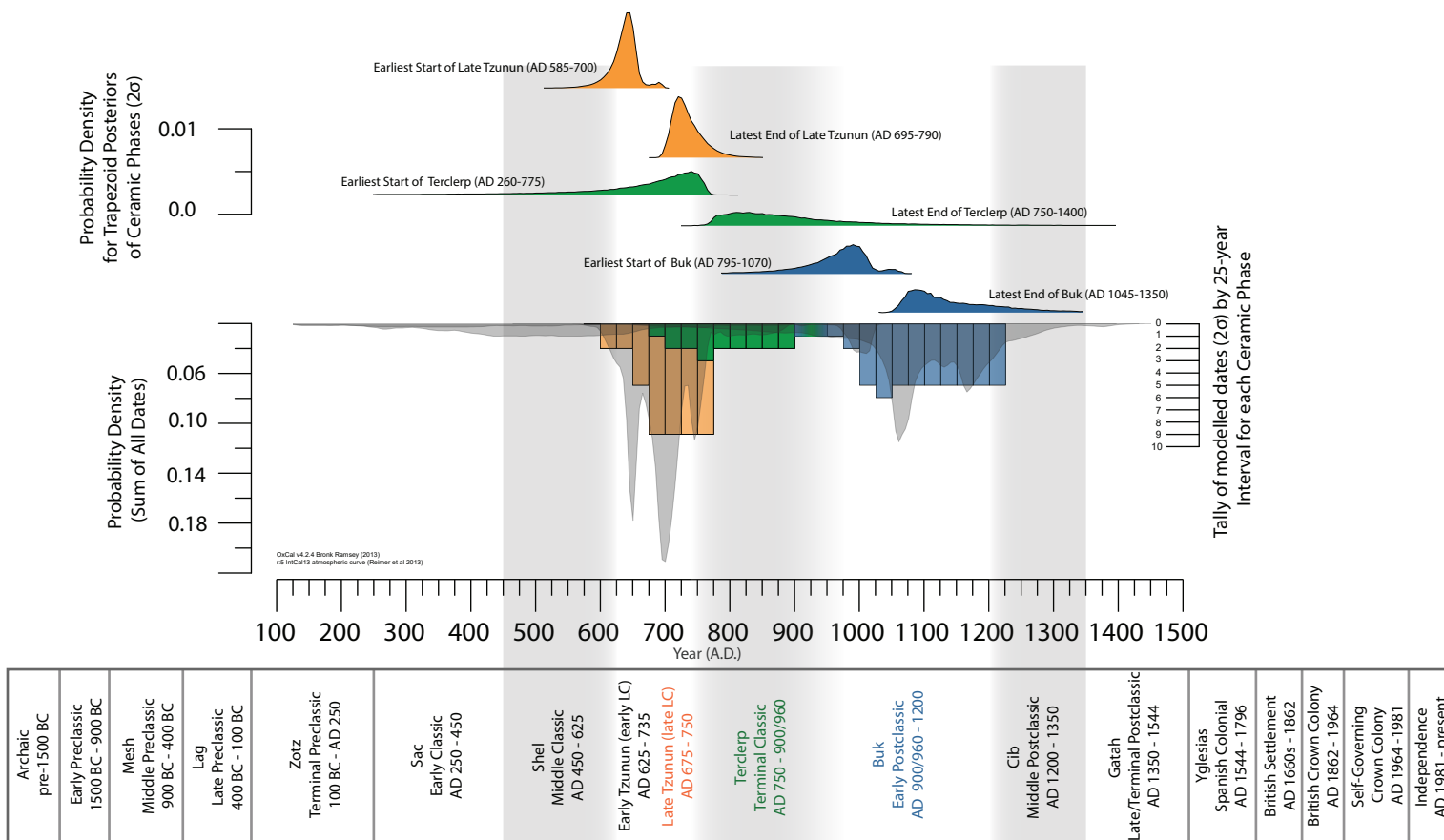
8

9 Figure 4 also includes a bar graph of 25-year binned intervals, which depict a tally of the number  
10 of samples falling within a given 25-year period (using individual 2-sigma ranges). For example,  
11 the modeled, 2-sigma range for sample OxA-18016(12) is AD 680-750, which means it was  
12 tallied for the four periods AD 675-699, AD 700-724, AD 725-749, and AD 750-774. Unlike  
13 sum probabilities, the 25-year bins are not informed by the radiocarbon calibration curve, giving  
14 each sample's entire probability equal weight. Because it is still influenced by the measurement's  
15 precision, however, this can become particularly deceptive. For example, the Buk phase sample  
16 from LA 177/1C (dated via conventional means in 1977 to AD 685-1215) would have counted  
17 in 22 bins— over 500 years— had it not been first constrained by the Bayesian model to AD 965-  
18 1215 prior to its incorporation in the tally. Both the sum and 25-year graphs are also biased by the  
19 archaeologist's choice of samples (Culleton 2008; Williams 2012; Contreras and Meadows 2014).  
20 For Lamanai's dates, both distributions suggest either a potential bias in sampling or a decrease  
21 in activity between the Terminal Classic and Postclassic periods, which will be discussed more  
22 below. Viewed appropriately, however, one could say the *sum* function and 25-year tally depict the  
23 “strength” of our knowledge about each phase and offer a simple method for identifying tipping  
24 points in cultural activity (for other successful examples see Hoggarth et al. 2015; Bettinger 2016;  
25 and Zahid et al. 2016).

26

27 Samples associated with the same ceramic phase were also evaluated using a trapezoidal distribution.  
28 For the construction sequences (Figures 3 and 5), the default uniform distribution is appropriate  
29 because they represent abrupt events like floors and renovations. For ceramic phases, however,  
30 modeling with a trapezoidal distribution simulates the more gradual changes seen in typological  
31 seriations (Brainerd 1951; Robinson 1951; Lee and Bronk Ramsey 2012). The trapezoidal model in  
32 OxCal uses Student's t-distribution to estimate the absolute beginning and absolute end parameters  
33 of the typology, giving it a wider range and less precision than the uniform model (though it  
34 approximates a uniform distribution as the transition lengths approach zero). However, because  
35 the duration is never completely 0, it avoids the abrupt transitions of uniform models and provides  
36 a more nuanced understanding of the gradations between phases. The trapezoidal distribution was  
37 applied in the manner described by Lee and Bronk Ramsey (2012; see also Lee et al. 2013), where  
38 three boundaries (start, middle, end) are anchored at the beginning and end of each phase. For  
39 these data, 17 posteriors from the earlier models associated with diagnostic ceramics (listed at the  
40 bottom of Figure 4) were saved as *.prior* files in OxCal and cross-referenced in a trapezoidal plot  
41 for each Lamanai phase. The three plots (Tzunun, Terclerp, and Buk) were then combined into one  
42 graph in Grapher 11 by Golden Software, Inc. Samples without definitive ceramic associations were  
43 not incorporated, including some posteriors from the earlier models (e.g., LA 139/1C, LA 115/2C,  
44 and LA 110/1C).

45



Lamanai Phase (revised from Powis 2002 and Graham 2011)

Samples Included in Ceramic Phases:

Late Tzunun: LA 1783 [OxA-17973], LA 1785/1 [OxA-17975], LA 1784 [OxA-17974], LA 1777 [combined OxA-17970 & OxA-17985],

LA 1798 [OxA-17976], LA 2525 [combined OxA-18019 & OxA-18018], LA 2522 [OxA-18016], LA 2532 [OxA-18020], LA 2524 [OxA-18017]

Terclerp: LA 1894/6 [OxA-18014], LA 1894/8 [OxA-18015], LA 1764 [OxA-17969]

Buk: LA 34/1C [combined GX-4660 & OxA-18021], LA 34/2C [GX-4661], LA 115/1C [combined GX-4663 & OxA-18022], LA 177/1C (GX-4670), LA 1742 [OxA-17968]



## 1 Results

### 2 Outliers in Structures N10-77 and N10-12 (Ottawa Group)

3 Of the 17 AMS <sup>14</sup>C dates from the Ottawa group, two were not refined in our Bayesian analysis, and  
4 another two were identified as outliers by the models. As mentioned above, LA 1778 and LA 1779  
5 were transposed secondary contexts inside bench features and therefore did not contain sufficient  
6 prior information to be included in a model. OxA-18018(14) from LA 2525 and OxA-18014(10)  
7 from LA 1894/6, on the other hand, were outlier dates that could not be reconciled in the standard  
8 (uniform) model because of low agreement with other samples in the same cache (see Appendix  
9 I for the probability values). Given their unexpectedly early ranges, these may have been cases of  
10 “old” (e.g., heirloom) wood, where the <sup>14</sup>C is much older than the associated event (Schiffer 1986;  
11 Kennett et al. 2002; Taylor and Bar-Yosef 2014:67-70). Because the samples were from caches of  
12 burnt materials, often following architectural renovations, there is a risk that the charcoal selected  
13 for AMS <sup>14</sup>C dating was derived from old building materials or other household items that predate  
14 the caching event.

15

16 There are several ways to handle outliers. The easiest way is to simply drop the sample altogether. If  
17 going that route, it is best to still include a *boundary* in the outlier’s place (which is also a way to check  
18 the accuracy of the “Charcoal” models described below). Another common and intuitive technique  
19 is to use the outlier as a *terminus post quem* (TPQ, using the *After* command). Unfortunately,  
20 however, the TPQ method is a coarse start/stop function that could push subsequent distributions  
21 out of agreement with their prior information (see Dee and Ramsey 2014:90).

22

23 A far better method for handling and evaluating outliers, described by Bronk Ramsey (2009a), is to  
24 run all the dates in OxCal by calling a normal distribution *OutlierModel(N(0,2),0,“t”)* instead of the  
25 standard, uniform model— where “t” means the timing of the event may have been wrong (rather  
26 than the radiocarbon measurement), and N calls a normal distribution with a mean of 0 and a  
27 standard deviation of 2. This will provide a rough probability on whether a given date is an outlier,  
28 as long as all samples are subsequently tagged with *Outlier(0.05)* to designate how often divergent  
29 iterations should be down-weighted (0.05 is used because 1 in 20 charcoal dates are older than the  
30 associated event) (Bronk Ramsey 2009a). This method identified LA 2525 [OxA-18018(14)] and  
31 LA 1894/6 [OxA-18014(10)] as likely outliers, confirming a similar output from the agreement  
32 index when using the standard model.

33

34 The latter method can be taken even further by using an exponential distribution (“Charcoal”) or  
35 a long-tail Student’s t-distribution (“General”) outlier model in OxCal (Bronk Ramsey 2009a; Dee  
36 and Bronk Ramsey 2014). The Charcoal model hinges on the idea that “old” dates could be better  
37 integrated into the sequence by using an *exponential* curve, where the density of dates from the  
38 same context would rise precipitously over the true date and then diminish exponentially. Rather  
39 than a rough TPQ, then, the “old” date creates a curving influence on the others, pushing them  
40 towards the ends of their distributions but still within the parameters of the model.

41

42 In using the outlier models with Lamanai’s dates, it was decided to keep all wood samples tagged  
43 with *Outlier(0.05)*, as all are expected to be at least one year older than the deposition event. The  
44 General and Charcoal models were then used in tandem, where the “good” dates were fitted to the  
45 General model shown below, and the potential “old wood” dates were fitted to the Charcoal model

1 at 1.0 (or 100% probability) (see Supplementary Materials for further descriptions of these models).

2

3 For the combined dates from LA 1777, LA 2525, and LA 1894, the syntax is slightly different.  
4 A “t-type” outlier model cannot be used on individual samples within the *R\_Combine* container  
5 because the assumptions of t-type models and *R\_Combine* are in conflict (i.e., either all of the  
6 samples should have the same measurement or they should not). This therefore requires the  
7 inclusion of a normal distribution within the *R\_Combine* operation (“SSimple” model), followed  
8 by a General outlier applied overall:

9

```
10 R_Combine(“Cache 2”)
```

```
11 {
```

```
12 {Outlier(“General”, 0.05)};
```

```
13 R_Date(“LA 1777 [OxA-17985(3)]”, 1402, 25) {Outlier(“SSimple”, 0.05)};
```

```
14 R_Date(“LA 1777 [OxA-17970(3)]”, 1409, 25) {Outlier(“SSimple”, 0.05)};
```

```
15 };
```

```
16
```

17 The combined dates from LA 1777 were always in high agreement, so the 0.05 outlier probability here  
18 is simply a safety check. For the other two combines in the other sequences, however, there was less  
19 agreement between samples. Excavators described 1894/6 and 1894/8 as having been likely placed  
20 in the cache at the same time. The initial (standard) model, however, indicated OxA-18018(14)  
21 from LA 2525 and OxA-18014(10) from LA 1894/6 as too old for their contexts, potentially due to  
22 old wood.

23

24 For LA 1894, Lentz identified 1894/6 as having a mixture of plant parts, including stems and tubers  
25 (similar to LA 1785), but all identifiable genera were trees (pine, logwood, and sapote), whereas its  
26 accompanying vessel, 1894/8, contained solely pine wood charcoal. However, the sample size of  
27 *Pinus caribaea* (57.25g) in 1894/6 was nearly six times larger than that of 1894/8 (9.38g), which may  
28 have left 1894/6 more susceptible to old wood, possibly explaining the ~80 year disparity between  
29 the two vessels. Because of the low agreement introduced into the model by combining these dates,  
30 the *R\_Combine* parameter was removed and they were instead *phased* using a 1.0 Charcoal outlier  
31 for 1894/6 and a 0.05 General model for 1894/8. This allowed both samples to (cautiously) continue  
32 informing the model and obtain a more robust posterior probability for how much 1894/6 is at  
33 odds with the sequence. As a result, LA 1894/6 now effectively functions as a *boundary*, reducing  
34 the impact of its measurement but still loosely influencing 1894/8.

35

36 For cache LA 2525, there were no comparable clues regarding why the two sample dates were so  
37 vastly different. In this case, they were from the same vessel, likely burnt in situ, and both identified  
38 as entirely *Pinus caribaea* charcoal by Lentz. Throughout extended experimentation with different  
39 models and parameters, sample OxA-18018(14) was repeatedly identified as an outlier, likely due  
40 to old wood (perhaps outer bark vs. inner heartwood). Because the overall agreement of the N10-  
41 12 model was 85.9%, the low agreement between the combined LA 2525 samples (26.5%) could be  
42 safely ignored, with OxA-18018(14) simply assigned a 1.0 probability in the SSimple model. This  
43 was considered more favorable than dropping OxA-18018(14) or phasing them separately, since  
44 they were from the same vessel. The final result of this analysis was the high-resolution model of  
45 N10-77 and N10-12 presented in Figure 3 and detailed in Appendix I.

1

## 2 **Structure N10-2**

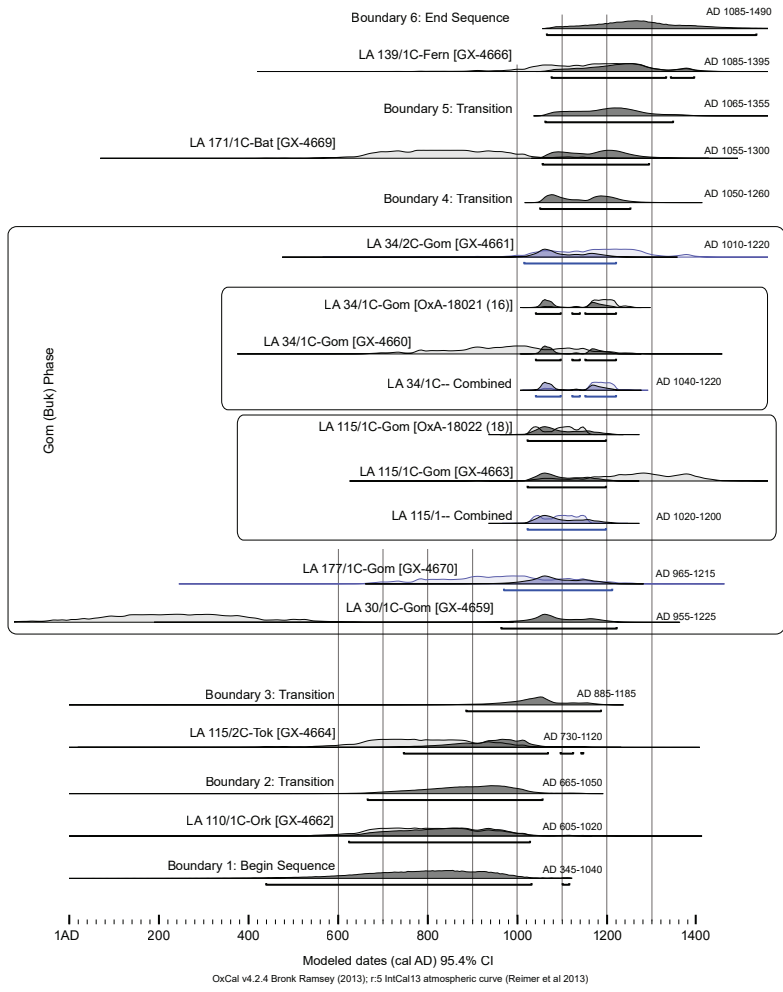
3 Excavation of Structure N10-2 (Pendergast 1981) showed that it was a focal point of Postclassic  
4 activity in the southern section of the site. Unfortunately, the samples analyzed in 1977 exemplify  
5 the low precision of conventional techniques, with distributions that are spread several centuries  
6 wide and virtually meaningless for the time scales relevant to Maya archaeology. What the N10-2  
7 sequence needed, therefore, were new, high-precision AMS <sup>14</sup>C dates that could be used to constrain  
8 (or replace) the originals. Along with the Ottawa Group samples in 2007, Graham submitted  
9 three previously dated (Geochron) samples from N10-2 as a test. Two of these provided a critical  
10 foundation for modeling the N10-2 sequence (Figure 5), but problems measuring the δ<sup>13</sup>C values  
11 of the third sample (from LA 34/2C) led to its rejection for re-dating. By linking the associated  
12 construction events to the re-dated samples using Bayesian techniques, the once expansive ranges  
13 in N10-2 have now been heavily constrained. The sequence is less robust than the Ottawa model  
14 because the only primary sampling contexts known are the two re-dated in 2007 (LA 34/1C and LA  
15 115/1C). Nonetheless, it is clear that the N10-2 radiocarbon sequence lends a strong line of support  
16 to the existing ceramic and architectural evidence for Postclassic continuity at Lamanai. Future  
17 sampling from other structures in this area and to the south would buttress this chronology further.  
18

19 The N10-2 Bayesian model was simpler than Ottawa's, with boundaries laid between each construction  
20 phase as a check, and only one phase containing multiple dates (the "Gom" construction phase,  
21 which is associated with diagnostic Buk ceramics; Graham 1987:85, fig. 5-h). Eleven Geochron  
22 <sup>14</sup>C dates and two ORAU AMS <sup>14</sup>C were available from Structure N10-2, of which eleven total were  
23 included in a Bayesian uniform model— the locations within the construction sequence for LA  
24 167/1C and LA 136/1C were not known (see Figure 5 for list of N10-2 construction phases). The  
25 samples from LA 171/1C and LA 30/1C were identified early on as outliers hundreds of years too  
26 early for their associated contexts (and roughly 1% chance of agreement with other samples around  
27 them; see Appendix I). As with the N10-77/N10-12 sequence, however, the use of outlier models  
28 allowed them to still contribute some information to the sequence.  
29

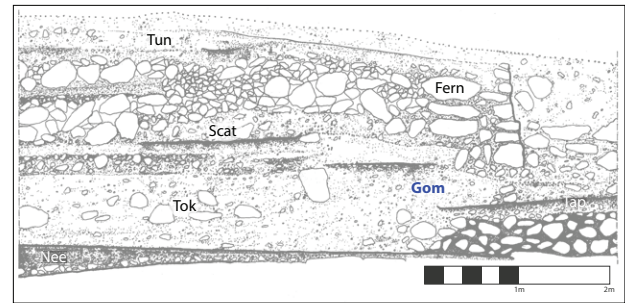
30 Some problems arose from vessels LA 34/1C and LA 34/2C in Cache 2 (samples GX-4660, GX-  
31 4661, and OxA-18021) and vessel LA 115/1C (GX-4663 and OxA-18022). LA 34/2C was from the  
32 same context as LA 34/1C, but when combined with the other samples, it strongly offset the overall  
33 model agreement. Because they are two separate vessels, this may be an indication that they were  
34 placed at separate times, but the sealed context had led excavators to believe they were concurrent  
35 (34/2C was instead phased with the combined 34/1C dates in the model).  
36

## 37 **Caching with Old, New, and Ancient Wood in N10-2**

38 As mentioned in the Ottawa modeling section, charcoal caches present the risk for old wood.  
39 Because conventional radiometric techniques required much larger sample sizes, the measurement  
40 taken by Geochron's gas-counting should have had a much higher risk of old wood effects than a  
41 newer AMS date from the same cache. For LA 115/1C, then, it was unusual that GX-4663 (AD 1035-  
42 1435) turned out to be *younger* than its new equivalent, OxA-18022 (AD 1020-1155). LA 115/1C  
43 was from wall construction that dates to the beginning of the 4<sup>th</sup> phase of N10-2 during the Early  
44 Postclassic. Pendergast's notes from 1976 described the contents of LA 115/1C as "probably wattle,"  
45 and Lentz identified it as "young wood," with mostly *Pinus caribaea* (pine) and a small amount of



Tun  
Fern  
(Prat)  
(Bat)  
Scat  
**Gom**  
Tap  
Tok  
(Zug)  
Nee  
(Ork)



South Section of N10-2  
with list of sequential construction phases (left)  
(parenthesis not shown in profile)



1 *Acromia aculeata* (palm). Because this material was likely assembled just prior to the construction  
2 event, some of it (probably the pine wood) may have been recycled from a previous structure. This  
3 would explain how it could be “young” when initially harvested but still older than the event being  
4 dated. The smaller size of the AMS  $^{14}\text{C}$  sample (OxA-18022) means that it had a higher chance of  
5 containing *purely* old wood, while the larger, conventional sample (GX-4663) averaged both old  
6 and new wood. Thus, both samples are older than the construction event, but the old Geochron  
7 sample is probably closer to the “true” date. Additionally, because GX-4663 was a combination  
8 of old and new wood, its  $2\sigma$  range still overlapped with OxA-18022, satisfying a chi-square test  
9 for compatibility (Ward and Wilson 1978) and allowing the samples to remain combined in the  
10 Bayesian model. Sample OxA-18022 was subsequently given a 1.0 outlier value and GX-4663 given  
11 a 0.5 value, granting GX-4663 more influence, but the actual construction event for LA 115/1C still  
12 likely occurred towards the later end of the modeled  $2\sigma$  range of AD 1020-1200.

13

14 For the LA 34/1C samples (GX-4660 and OxA-18021), the older, conventional date does appear  
15 to have an “old wood” effect, given that it is significantly older than its AMS equivalent. LA 34/1C  
16 was a cache containing stick-like figurines overlying maize and beans, burnt as an offering at the  
17 abandonment of the 4<sup>th</sup> phase of N10-2. Both Pendergast in 1976 and Lentz in 2007 noted that  
18 the samples consisted primarily of charred maize. GX-4660 was also one of the samples for which  
19 Geochron had provided the corrected date, though not the actual  $\delta^{13}\text{C}$  value. Thus, we were able  
20 to input the corrected and uncorrected dates into Calib’s fractionation spreadsheet, as described  
21 above (Stuiver and Reimer 2015), and backwards-calculate the original  $\delta^{13}\text{C}$  readings for that  
22 particular sample. Geochron appears to have measured  $-17.4\text{‰}$   $\delta^{13}\text{C}$  for GX-4660, which is exactly  
23 where you would expect a mix of maize ( $-10\text{‰}$ ) and wood ( $-24\text{‰}$ ) (Stuiver and Polach 1977:358).  
24 The  $\delta^{13}\text{C}$  reading for the smaller AMS sample (OxA-18021) was  $-9.62\text{‰}$   $\delta^{13}\text{C}$ — pure maize. Thus,  
25 the small amount of wood that was included in GX-4660 (e.g., pieces of the stick figurines) likely  
26 contained “old wood,” causing the  $^{14}\text{C}$  determination to be older than OxA-18021. As in the 115/1C  
27 case, both 34/1C samples passed a chi-square test for compatibility (again, the larger sample size  
28 of the conventional date lessened the “old wood” effect), but their influence on each other caused  
29 high-enough disagreement within the overall model that sample GX-4660 had to be assigned a  
30 1.0 outlier value. Because OxA-18021 was purely maize, its date is likely very close to the original  
31 caching event, with a modeled date of AD 1040-1220. Since, as described above, LA 115/1C dates  
32 to the beginning of this construction phase and likely occurred within the 12<sup>th</sup> century, the latter  
33 portion of the 34/1C modeled date (AD 1150-1220, CI: 44.3%) appears more plausible than is  
34 granted by the final model. In fact, the unmodeled date for OxA-18021 was AD 1150-1255 (CI:  
35 91.9%), indicating that the sample’s placement within the Bayesian model may actually have had a  
36 deleterious effect on its accuracy, in part because of interactions with the radiocarbon curve (see  
37 Appendix I and Supplementary Materials for more).

38

39 One last note should be made regarding GX-4659, the extreme outlier from a Buk phase lot (LA  
40 30/1C) in N10-2. This sample appears to date roughly 1000 years earlier than its associated deposit,  
41 making its measurement wholly ignored in any model. Though problematic for our purposes, it  
42 should be emphasized that such aberrant outliers are not “bad” dates. Indeed, the accuracy of the  
43 measurement is not in doubt. Rather, the antiquity of the date causes us to wonder: what kind of  
44 wood was being burned in this cache that was so incredibly ancient? It is unlikely that ancient wood  
45 would be readily accessible as firewood from common house materials or midden— particularly in

1 a tropical climate. It seems more plausible that this cache contained pieces of discarded heirlooms  
2 or older construction materials (e.g., lintels) from recently dismantled or ritually terminated  
3 structures. Further analysis of the species of wood present in this cache, its contextual information,  
4 and continued high-precision dating may provide additional clues to the human behavior  
5 underlying this peculiar sample.

6

## 7 **Discussion**

8 The results of the chronometric work presented above have implications for the Late Classic/Terminal  
9 Classic ceramic chronologies at Lamanai, as well as for the timing of the Boulders construction  
10 effort in the Ottawa Group. The original scenario for Plaza N10[3] held that sometime between  
11 AD 950-1050, the courtyard was filled and the masonry structures of the Ottawa Group were razed  
12 and covered—the Boulders phase (Pendergast 1986:232). Later excavations re-dated the Boulders  
13 construction to the Terminal Classic (ca. A.D. 800) based on the stratigraphy of courtyard infill and  
14 primary ceramics associated with N10-77 (Graham 2004). The refined chronology presented here  
15 confirms that the infilling of the courtyard dates to sometime around the end of the 8<sup>th</sup> century.  
16 The radiocarbon dates for the final occupation of N10-77 (Floor 1) date to AD 680-755, with a final  
17 termination (razing) event shortly after, between AD 700-815; the Boulders phase likely began just  
18 after that termination. Two diagnostic vessels associated with Floor 1 provided ideal markers for a  
19 true Late Classic to Terminal Classic transition: an upturned, glossy-black, Late Classic (Tzunun)  
20 vase filled with burnt wood fragments (LA 1785/1) and sealed by the final floor; followed by a  
21 diagnostic Terminal Classic (Terclerp) basal-break bowl stamped into the burnt floor during the  
22 structure's termination (LA 1764) (Graham 2004:236–237). Their associated samples date to AD  
23 655-730 (CI:93.2%) and AD 695-770 (CI:95.4%), respectively (Figure 6). While significant overlap  
24 exists between these dates, there are clear ceramic and stratigraphic differences between the Late  
25 Classic and Terminal Classic, including the shift from masonry to wood construction mentioned  
26 above (Graham 2004).

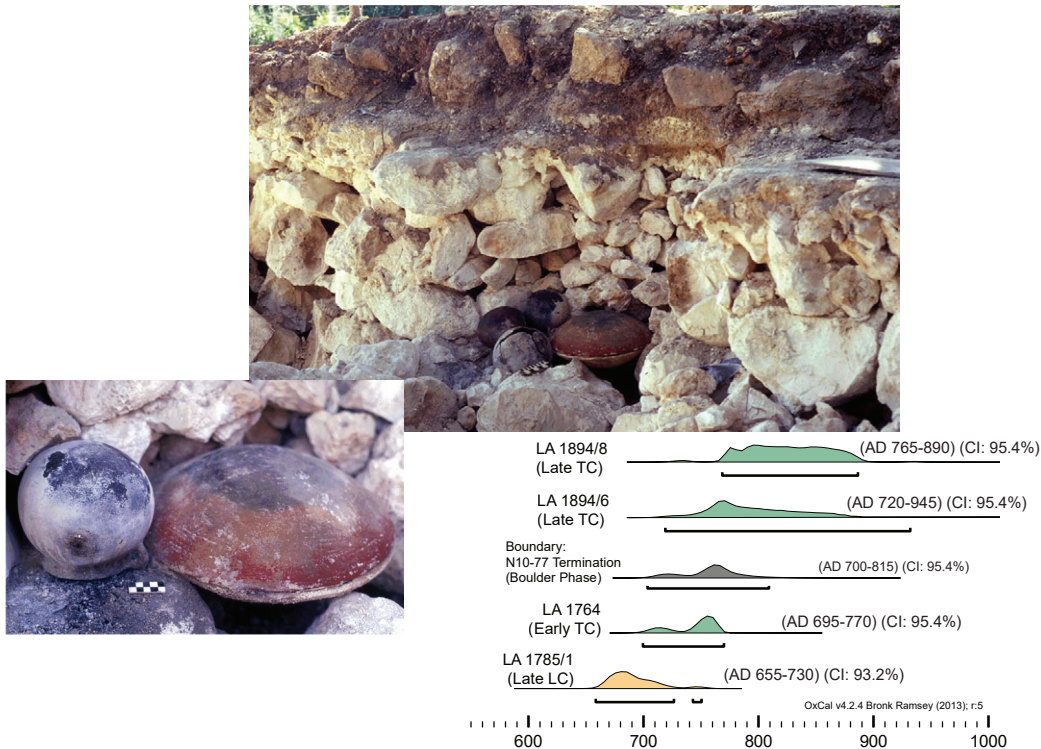
27

28 Above the Boulders phase, additional carbonized caches were found in the core of the masonry  
29 platform supporting N10-12/1st. The platform, as noted above, was built as the courtyard was  
30 filled, so samples within it provide a potential end date for the Boulders construction effort. The  
31 caches associated with N10-12/1st comprise either monochrome red-slipped or polychrome lip-to-  
32 lip shallow ceramic bowls (LA 1894/8 and 1894/6)— characteristic of Lamanai during the Terminal  
33 Classic. The samples from LA 1764 (the burned basal-break vessel) and LA 1894/8 therefore serve  
34 as early and late markers for the Terminal Classic period. The boundary calculation estimates the  
35 first occupation of N10-12 occurred between AD 700-815, and the date for LA 1894/8 is AD 765-  
36 890. Figure 6 highlights these important chronological markers.

37

38 When combined with the other dates associated with Late Tzunun (Late Classic) pottery in  
39 N10-77, these new (modeled) dates now push the Late Tzunun phase back 60 years earlier, from  
40 a previous start time around AD 735 to AD 675. Likewise, the start of the subsequent Terclerp  
41 (Terminal Classic) ceramic phase may be pushed back roughly 25 years, from a start of AD 775 to  
42 AD 750 (ending sometime between AD 900-960). These changes are reinforced by the probability  
43 density graphs (Figure 4), which provide the combined probabilities for all samples associated with  
44 diagnostic Tzunun (n=9), Terclerp (n=3), and Buk (n=5) ceramics.

45



1 For the N10-77/N10-12 sequence, the only Early Postclassic date is from LA 1742. This sample  
 2 derives from a concentration of Zakpah sherds and charcoal that were determined to be intrusive  
 3 into the Boulder core and probably part of a burial in the N10-12 platform just above (Pendergast  
 4 1982a; Graham 1987; Graham 2004; Wrobel and Graham 2015). Given the tendency of material  
 5 to shift amongst the stones of the core, however, we cannot be as certain of this association as we  
 6 can with other samples. Ceramic evidence indicates that the structure was occupied into the Late  
 7 Postclassic, but no charcoal was recovered from any later contexts.

8

9 The sample from the LA 1742 burial cache also contained pine as the main material. *Pinus caribaea*  
 10 is a prevalent wood type in Terminal Classic caches at the site but has only been found in two other  
 11 Early Postclassic contexts, both of which likely contained old wood: LA 115/1C and LA 34/1C  
 12 (discussed above). Although caching continued through the Colonial period (Graham, Pendergast,  
 13 and Jones 1989), the practice appears to have decreased following the Terminal Classic, when the  
 14 main structural interments became human burials instead of ceramic caches (Pendergast 1998). It  
 15 is interesting that Rushton et al. (2013:491) observed declining pollen signals for pine during times  
 16 of major construction, particularly AD 600-975, but saw a resurgence after AD 1000. It appears that  
 17 the prevalence of *Pinus* caching exhibits an inverse relationship to the pollen record, suggesting that  
 18 the decline of its use in caches may be correlated to its heavy exploitation as timber and firewood  
 19 (Thompson 1930; Vogt 1981; Rushton, Metcalfe, and Whitney 2013) as well as for ritual use (Lentz  
 20 et al. 2005; Morehart et al. 2005; Prufer and Dunham 2009; Robinson and McKillop 2013). Perhaps  
 21 confirming its use for construction, wall materials sampled in LA 115/1C contained old *P. caribaea*  
 22 wood, and the burnt stratum sampled from N10-77 (LA 1764) contained only pine. Caches LA  
 23 1894/8, 2525, and 34/1C also contained old pine wood. Thus, if *P. caribaea* was a preferred source of  
 24 timber at Lamanai, it is unsurprising that old wood (e.g., from house renovations or terminations)

1 was so strongly represented in caches.

2

3 Finally, the broadest impact of the chronometric work presented here is perhaps the continuity  
4 demonstrated between the Terminal Classic and Postclassic periods at Lamanai. Though the dates  
5 available suggest decreased activity in the site core during the 10<sup>th</sup> century AD, there is clearly  
6 overlap between the Terclerp and Buk phases, as shown in the N10-12 sequence (Figure 3). The  
7 “lull” may be, in part, an artifact of the number of samples measured from the Terclerp phase. A  
8 larger sample of <sup>14</sup>C AMS dates from this transition would resolve the ambiguity. Likewise, the latest  
9 radiocarbon date available (GX-4666 from LA 139/1C in N10-2) provides only tentative evidence  
10 for occupation after ~AD 1300, but the ceramic chronology at the site continues with the Gatah  
11 (AD 1350-1544) and Yglesias (AD 1544-1700) phases, for which no radiocarbon dates yet exist  
12 (Graham 2011). The problem— one faced at many Postclassic sites (Masson and Mock 2004:378)—  
13 is the paucity of well-sealed primary contexts that can yield organic samples like those from the  
14 lower levels of the Ottawa Group. Additionally, the Terminal Classic is characterized at many sites  
15 by a transition in construction techniques— notably a reduction in masonry architecture. As a  
16 result, several centuries of occupation following the Late Classic are often represented by only thin  
17 scatters of debris that are difficult or impossible to discern. These issues continue to present obstacles  
18 for the selection of high-quality samples from Postclassic contexts and highlight the potential for  
19 alternative dating programs, such as those that directly date human burials from primary contexts  
20 (Hoggarth et al. 2014; Kennett et al. 2015).

21

## 22 **Conclusion**

23 This paper presented 19 new radiocarbon dates for the site of Lamanai and demonstrated the  
24 power of Bayesian analytical techniques for chronological refinement of old and new dates. The  
25 new cluster of radiocarbon samples from the Ottawa Group corroborate existing stratigraphic  
26 and ceramic records that the years spanning the Late Classic to Postclassic periods at Lamanai  
27 were characterized by continuous activity, albeit with changing socio-cultural mores. The massive  
28 Boulder construction effort and subsequent shift to wood construction indicate that the priorities  
29 of Lamanai’s elites began to change as early as the end of the 8<sup>th</sup> century AD (Graham 2004).  
30 This was a time of frenetic activity across the Maya lowlands when many cities experienced peak  
31 population levels (Sabloff and Henderson 1993; Adams 2004; Hammond and Tourtellot 2004; Rice  
32 and Forsyth 2004; Robichaux and Houk 2005; Sullivan et al. 2007; Ebert et al. 2014) tempered by  
33 drought, increased warfare, and political fragmentation (Hodell et al. 2005; Kennett et al. 2012)  
34 and the rise of the northern Lowlands (Hoggarth et al. 2015). Lamanai’s endurance was never  
35 believed a complete anomaly (Pendergast 1986:226), and we now know that many communities  
36 survived, adapted, and endured into the Postclassic period (Webster 2002; Demarest, Rice, and  
37 Rice 2004; Aimers 2007). The evidence presented here refines the chronology for perhaps the most  
38 tenacious of such communities, and may have implications for other sites in the region whose  
39 ceramic traditions and political affiliations were tied to those of Lamanai.

40

## 41 **Acknowledgments**

42 The authors would like to thank two anonymous reviewers for their thorough proofreading and  
43 insightful commentary, as well as Brendan Culleton for his guidance through the intricacies of  
44 Bayesian modeling and OxCal programming. Thanks also to Thomas Higham for his generous  
45 advice with sampling strategies and outlier modeling, as well as the staff at ORAU for their



1 exceptional work in the radiocarbon analysis. The radiocarbon determinations from Oxford were  
2 funded by the NERC's National Radiocarbon Facility (NF/2007/1/11). Laboratory support to DJK  
3 was provided by the NSF Archaeometry program (BCS-1460369). Finally, the Belize Institute of  
4 Archaeology (formerly Department of Archaeology) has generously granted permits for our many  
5 years of work at Lamanai.  
6

## Endnotes

1. Unless otherwise noted, all dates from Lamanai refer to radiocarbon dates calibrated in OxCal 4.2.4 (Bronk Ramsey 2014a), as described in the Methods section.
2. Lamanai's ceramic phases are based on stratigraphic relationships rather than a type-variety system— see Aimers and Graham (2013) for a general discussion. For specific phases, see: Pendergast (1982a) for Buk; Graham (1987) and Howie (2005; 2012) for Buk and Terclerp; and Powis (2002) for Preclassic. Other phases are not as well-described, but see Pendergast (1981).
3. "Corrected" here is defined as the correction derived from measured  $\delta^{13}\text{C}$  ( $^{13}\text{C}/^{12}\text{C}$  or converted from  $^{14}\text{C}/^{12}\text{C}$ ), normalized to -25‰ VPBD. See Table S3 for corrections made to these dates.
4. As a result of this imprecision, only the lab numbers and a summary of the data were published at the time (Pendergast 1981:49).
5. At ORAU, as at many labs, if a sample cannot be measured during stable isotope analysis, it will be rejected on the basis that any date attached would be improperly corrected and likely misleading (ORAU website 2015).
6. A full explanation of Bayesian techniques is beyond the scope of this paper, but interested readers should consult seminal works by Buck et al. (1991; 1996), Steier and Rom (2000), Bayliss (2009), and Bronk Ramsey (2009b).

Lab # (Sample #)	Lot/Vessel #	Sample Material	Sample Weight	Provenience	Context	Associated Artifacts	Associated Ceramic Phase	$\delta^{13}\text{C}$	Corrected Radiocarbon Age (BP), $1\sigma$	Unmodelled calAD		Modelled calAD	
										range	P	range	P
<b>N10-12</b>													
----	<i>Boundary End Occupation</i>	----	----	<i>N10-12</i>	----	----	----	----	----	----	----	<i>970-1385</i>	<i>83.3%</i>
OxA-17968 (1)	LA 1742	charcoal ( <i>Pinus caribaea</i> ) [Lentz]	14.63g	N10-12 Boulder Core [likely during Floor 1 (N10- 12/2nd)]	Within boulder core, on primary axis, just below Buk burial; fill between N10-78 and N10-77	Concentration of charcoal and sherds from a Buk pedestal jar (normally associated with burials)	Buk	-25.93	1050 $\pm$ 24	900-925 960-1025	5.0% 90.4%	<b>900-920</b> <b>960-1030</b>	<b>2.2%</b> <b>93.2%</b>
----	<i>Boundary Early PC</i>	----	----	<i>N10-12</i>	----	----	----	----	----	----	----	<i>830-1020</i>	<i>95.4%</i>
OxA-18014 (10)	LA 1894/6	<i>Pinus caribaea</i> <i>Manilkara sapota</i> Angiosperm <i>Haematoxylon campechianum</i> Dicot stem tuber [Lentz]	57.25g 0.09g 2.77g 0.25g 0.02g 0.06g	N10-12/1st Floor 2 Cache 8	Contents of a ceramic vessel #6  <i>Low combined agreement with OxA-18015, A=15.4%</i>	Ceramic jar #6 also containing Spondylus shell fragments, ceramic sherds, bone fragments, and a rodent tooth)	Terclerp	-26.27	1282 $\pm$ 26	665-770	95.4%	<b>720-945</b>	<b>95.4%</b>
OxA-18015 (11)	LA 1894/8	charcoal ( <i>Pinus caribaea</i> ) [Lentz]	9.38g	N10-12/1st Floor 2 Cache 8	Contents of shallow polychrome dish #8	Lip-to-lip shallow bowls also containing a bird bone fragment and a dirt concretion both painted with cinnabar	Terclerp	-26.01	1206 $\pm$ 26	715-745 765-890	6.1% 89.3%	<b>765-890</b>	<b>95.4%</b>
<b>N10-77</b>													
----	<i>Boundary N10-77 Termination, Start of N10-12</i>	----	----	<i>N10-77, Room B2</i>	----	----	----	----	----	----	----	<i>700-815</i>	<i>95.4%</i>
OxA-17969 (2)	LA 1764	charcoal ( <i>Pinus caribaea</i> ) [Lentz]; may have included perishable furnishings like wooden objects, mats, and textiles	0.57g	N10-77 Room B2	Burnt stratum covering the final floor of B2 and B3 (sample from B2) [Boulder Core likely just after]	Early TC vessel	Early Terclerp	-26.81	1312 $\pm$ 25	655-725 740-770	70.4% 25.0%	<b>695-770</b>	<b>95.40%</b>
----	<i>Boundary Final Floor-- Start of TC</i>	----	----	<i>N10-77 Room B2</i>	----	----	----	----	----	----	----	<i>685-765</i>	<i>95.4%</i>
OxA-17973 (6)	LA 1783	charcoal ( <i>Pinus caribaea</i> ) [Lentz]	130.91g	N10-77 Room B2 Cache 5	Cavity in penultimate floor, just west of cache 2 (LA 1777)	Large carbon deposit	End of Early Tzunun/Start of Late	-26.08	1280 $\pm$ 24	670-770	95.4%	<b>660-750</b>	<b>95.4%</b>
OxA-17975 (8)	LA 1785/1	<i>Pinus caribaea</i> (charcoal) <i>Sapotaceae</i> sp. (charcoal) [Lentz]	21.3g 1.5g	N10-77 Room B2 Cache 4	Cavity in penultimate floor; wooden artifact within grooved black vessel #1 placed upside down	Grooved black vase #1 (diagnostic LC)	End of Early Tzunun/Start of Late	-26.73	1297 $\pm$ 25	660-730 735-770	63.1% 32.3%	<b>655-730</b> <b>740-755</b>	<b>93.2%</b> <b>2.2%</b>
OxA-17974 (7)	LA 1784	charcoal ( <i>Pinus caribaea</i> ) [Lentz]	5.17g	N10-77 Room B2 Cache 3	Shallow cavity in penultimate floor of the B2 doorway	Obsidian and sherds	End of Early Tzunun/Start of Late	-26.06	1304 $\pm$ 25	660-725 735-770	65.9% 29.5%	<b>655-725</b> <b>740-755</b>	<b>92.7%</b> <b>2.7%</b>
OxA-17970 (3)	LA 1777	charcoal ( <i>Pinus caribaea</i> ) [Lentz]; believed to have been inside a perishable container such as gourd or wooden bowl	1.87g	N10-77 Room B2 Cache 2	Cavity in penultimate floor (beginning of the final occupation)  <i>Acomb= 125.9</i>	Jade fragments, Spondylus, and obsidian	End of Early Tzunun/Start of Late	-25.68	1409 $\pm$ 25	600-665	95.4%	<b>620-665</b>	<b>95.4%</b>
OxA-17985 (3)								-26.62	1402 $\pm$ 25	600-665	95.4%		
----	<i>Boundary Penultimate Floor</i>	----	----	<i>N10-77 Room B2</i>	----	----	----	----	----	----	----	<i>530-665</i>	<i>95.4%</i>

Lab # (Sample #)	Lot/Vessel #	Sample Material	Sample Weight	Provenience	Context	Associated Artifacts	Associated Ceramic Phase	$\delta^{13}\text{C}$	Corrected Radiocarbon Age (BP), $1\sigma$	Unmodelled calAD		Modelled calAD	
										range	P	range	P
OxA-17971 (4)	LA 1778	charcoal ( <i>Manilkara zapota</i> ) [Lentz]	0.71g	N10-77 Room B3	Core of Bench 3 (transposed fill)	----	Early Tzunun	-25.32	1423 $\pm$ 25	585-660	95.4%	Not included in model due to context	
----	Boundary Floor 1 End	----	----	N10-77 Room C	----	----	----	----	----	----	----	690-765	95.4%
OxA-17976 (9)	LA 1798	charcoal ( <i>Pinus caribaea</i> ) [Lentz]	49.24g	N10-77 Room C Floor 1 Cache 8	Cut into Floor 1 and capped with stone at upper level (during use-life of Floor 1)	----	Late Tzunun	-26.06	1284 $\pm$ 25	665-770	95.4%	685-760	95.4%
OxA-18019 (14)	LA 2525	charcoal ( <i>Pinus caribaea</i> ) [Lentz]	19.14g	N10-77 Room C Floor 1 Cache 13	Cut into Floor 1 and capped by mortar layer (during use-life of Floor 1)  <i>Low model agreement for OxA-18018, A=26.5; Acomb=82.4</i>	Small facing stones (with quartzite fragments)	Late Tzunun	-26.06	1282 $\pm$ 26	665-770	95.4%	685-760	95.4%
OxA-18018 (14)										645-715	81.4%		
----	Boundary Floor 2 End	----	----	N10-77 Room C	----	----	----	----	----	----	----	680-755	95.4%
OxA-18016 (12)	LA 2522	charcoal ( <i>Pinus caribaea</i> ) [Lentz]; may have been inside a perishable container such as gourd or wooden bowl	4.74g	N10-77 Room C Floor 1 Cache 10	Sealed by Floor 1	----	Late Tzunun	-26.15	1260 $\pm$ 26	665-780 790-805 810-825 840-865	90.5% 1.7% 0.9% 2.3%	680-750	95.4%
OxA-18020 (15)	LA 2532	charcoal ( <i>Pinus caribaea</i> ) [Lentz]	3.68g	N10-77 Room C Floor 2 Cache 19	Center of eastern doorway, cut into penultimate Floor 2 and capped by Floor 1	----	Late Tzunun	-28.33	1240 $\pm$ 26	685-780 785-875	64.5% 30.9%	680-750	95.4%
OxA-18017 (13)	LA 2524	charcoal ( <i>Pinus caribaea</i> ) [Lentz]; burned in situ	7.03g	N10-77 Room C Floor 2 Cache 12	Cut into Floor 2, west of the centre of the eastern doorway, sealed by a mortared stone slab	----	Late Tzunun	-26.06	1275 $\pm$ 26	670-775	95.4%	675-750	95.4%
OxA-17972 (5)	LA 1779	charcoal ( <i>Pinus caribaea</i> ) [Lentz]	1.60g	N10-77 Room C	Core of Bench 4, room-length extension (transposed fill)	LC ceramics (not diagnostic), faunal bone	Tzunun	-26.28	1367 $\pm$ 26	615-685	95.4%	Not included in model due to context	
----	Boundary Floor 2	----	----	N10-77 Room C	----	----	----	----	----	----	----	660-750	95.4%
<b>N10-2</b>													
----	Boundary 6: End Sequence	----	----	N10-2	----	----	----	----	----	----	----	1085-1490	95.4%
GX-4666	LA 139/1C	Coarse wood charcoal [Pendergast]	----	N10-2	From the core of the 'Fern' construction phase.	----	----	-24 <sup>A</sup>	826 $\pm$ 134*	905-920 965-1410	0.5% 94.9%	1085-1395	95.4%
----	Boundary 5: Transition	----	----	N10-2	----	----	----	----	----	----	----	1065-1355	95.4%
GX-4669	LA 171/1C	Coarse wood charcoal [Pendergast]	----	N10-2	From the core of 'Bat' construction phase  <i>Low agreement with standard model (A=13.2%, P=0.9)</i>	----	----	-24 <sup>A</sup>	1191 $\pm$ 129*	600-1050 1085-1125 1135-1150	93.4% 1.6% 0.5%	1055-1300	95.4%
----	Boundary 4: Transition	----	----	N10-2	----	----	----	----	----	----	----	1050-1260	95.4%
GX-4661	LA 34/2C	charred beans [Pendergast]  New (failed) sample contained: <i>Phaseolus vulgaris</i> <i>Pinus caribaea</i> Arecaceae Angiosperm [Lentz]	3.96g 18.61g 3.04g 3.92g	N10-2, 4th, Cache 2	Gom Phase South side of stair block	----	Buk (Gom phase)	-25.6*	830 $\pm$ 120	975-1330 1340-1395	90.8% 4.6%	1010-1220	95.4%

Lab # (Sample #)	Lot/Vessel #	Sample Material	Sample Weight	Provenience	Context	Associated Artifacts	Associated Ceramic Phase	$\delta^{13}\text{C}$	Corrected Radiocarbon Age (BP), 1 $\sigma$	Unmodelled calAD		Modelled calAD	
										range	P	range	P
OxA-18021 (16)	LA 34/1C	charred kernels ( <i>Zea mays</i> ) charred cobs ( <i>Zea mays</i> ) <i>Pinus caribaea</i> 2 charred beans ( <i>P. vulgaris</i> ) [Lentz]	5.33g 2.28g 2.16g 0.01g	N10-2, 4th, Cache 2	Gom Phase South side of stair block  <i>A=56.7%, Acomb=61.2</i>	Freshwater snail shell	Buk (Gom phase)	-9.62	856 ± 25	1055-1080	3.5%	1040-1100 1120-1140 1150-1220	47.8% 3.3% 44.3%
		1150-1255	91.9%										
GX-4660		Charcoal, mostly maize [Pendergast]	----										
OxA-18022 (18)	LA 115/1C	<i>Pinus caribaea</i> <i>Acrocomia aculeata</i> (endocarp) (young wood) [Lentz]	12.41g 1.71g	N10-2, 4th	Gom Phase Wall construction (contained "old wood," see text)	----	Buk (Gom phase)	-26.16	950 ± 25	1020-1155	95.4%	1020-1200	95.4%
		760-1225	93.4%										
GX-4663		Charcoal fragments; probably wattle and possibly some other wood as well [Pendergast]	----		<i>A=47.9%, Acomb=51.2</i>								
GX-4670	LA 177/1C	wood charcoal [Pendergast]	----	N10-2	From a posthole in the 'Gom' construction phase	----	Buk (Gom phase)	-24 <sup>^</sup>	1061 ± 124*	685-750 760-1215	5.2% 90.2%	965-1215	95.4%
GX-4659	LA 30/1C	wood charcoal fragments [Pendergast]	----	N10-2	From the core of the Gom construction phase; <i>Low agreement with standard model (A=1.2%, P=0)</i>	----	Buk (Gom phase)	-24 <sup>^</sup>	1786 ± 139*	90BC-AD565	95.4%	955-1225	95.40%
GX-4668	LA 167/1C	fine wood charcoal from sample with ashes [Pendergast]	----	N10-2	From a hearth in the 'Prat' construction phase.	----	----	-24 <sup>^</sup>	926 ± 129*	775-1385	95.4%	Not included in model due to unknown placement of 'Prat' phase	
----	<i>Boundary 3: Transition</i>	----	----	----	----	----	----	----	----	----	----	875-1185	95.4%
GX-4664	LA 115/2C	coarse wood charcoal [Pendergast]	----	N10-2	From atop the ballast of the floor of the 'Tok' construction phase	----	----	-24 <sup>^</sup>	1251 ± 129*	545-1025	95.4%	730-1070 1095-1120	94.3% 1.1%
----	<i>Boundary 2: Transition</i>	----	----	----	----	----	----	----	----	----	----	655-1050	95.4%
GX-4662	LA 110/1C	'fibrous' wood charcoal [Pendergast]	----	N10-2	From the core, in an area where the floor had been chopped, just east of 'Ork'	----	----	-25.3*	1235 ± 130	550-1035	95.4%	605-1020	95.4%
GX-4665	LA 136/1C	charcoal fragments, possibly palm wood [Pendergast]	----	N10-2	From the core of construction unit 'Zug;'	----	----	-26.2*	1690 ± 125	55-600	95.4%	Not included in model due to unknown placement of 'Zug' phase	
----	<i>Boundary 1: Begin Sequence</i>	----	----	----	----	----	----	----	----	----	----	345-1040	95.4%
<b>Other Dates</b>													
GX-4671	LA 207	wood charcoal [Pendergast]	----	N10-9 2nd Terrace	Stairside, outset renewal	----	----	-24 <sup>^</sup>	1611 ± 134*	125-660	95.4%	----	----
GX-4672	LA 208	wood charcoal [Pendergast]	----	N10-9, Cache 2	Rear room of building	----	----	-24 <sup>^</sup>	1511 ± 134*	215-775	95.4%	----	----
GX-4673	LA 209	wood charcoal [Pendergast]	----	N10-9	From the northeast corner base	----	----	-24 <sup>^</sup>	1401 ± 188*	240-1020	95.4%	----	----
GX-4667	LA 166	wood charcoal [Pendergast]	----	N10-7	Underneath Burial #3	----	----	-24 <sup>^</sup>	1526 ± 134*	215-770	95.4%	----	----
----	Stela 9	----	----	N10-27	Defaced monument erected by the "Supreme Lord of the East", honoring the death of his 17 year-old son (Tzik'in Xook), possibly making N10-27 a memorial (Closs 1988, Pendergast 1988; Martin et al. 2004)	----	Covered by Terclerp/Early Buk midden and 5 burials	----	AD 625	625	----	----	----

Calibrated with OxCal v4.2.4 (Bronk Ramsey 2013) and IntCal13 northern atmospheric curve (Reimer et al. 2013); all calibrations rounded to 5

\*Estimated, based on Stuiver and Reimer 2015, see text and Table S3; ^Based on Stuiver and Polach 1977; Samples with gold lab # contained outlier distributions that were down-weighted in 100% of model iterations

## References Cited

- Adams, R.E.W; Fred Valdez Jr.; Brett A Houk; and Ruth Matthews. 2004. Transformations, Periodicity, and Urban Development in the Three Rivers Region. In: Demarest AA, Rice PM, Rice DS, editors. *The Terminal Classic in the Maya Lowlands: Collapse, Transition, and Transformation*. Boulder: University Press of Colorado. p. 324–341.
- Aimers JJ. 2007. What Maya Collapse? Terminal Classic Variation in the Maya Lowlands. *J Archaeol Res* 15: 329–377.
- Aimers JJ, Graham E. 2013. Type-Variety on Trial: Experiments in Classification and Meaning Using Ceramic Assemblages from Lamanai, Belize. In: Aimers JJ, editor. *Ancient Maya Pottery: Classification, Analysis, and Interpretation*. Gainesville, FL: University Press of Florida. p. 91–106.
- Aimers JJ, Hodell D. 2011. Societal collapse: Drought and the Maya. *Nature* 479: 44–45.
- Andres CR, Pyburn KA. 2004. Out of sight: The Postclassic and Early Colonial Periods at Chau Hiix, Belize. In: Demarest AA, Rice PM, Rice DS, editors. *The Terminal Classic in the Maya Lowlands: Collapse, Transition, and Transformation*. Boulder: University Press of Colorado. p. 402–423.
- Bayliss A. 2009. Rolling out revolution: using radiocarbon dating in archaeology. *Radiocarbon* 51:123–47.
- Bettinger RL. 2016. Prehistoric hunter–gatherer population growth rates rival those of agriculturalists. *PNAS* 113:812–814.
- Brainerd GW. 1951. The Place of Chronological Ordering in Archaeological Analysis. *American Antiquity* 16:301–313.
- Brock F, Higham T, Ditchfield P, Bronk Ramsey C. 2010. Current pretreatment methods for AMS radiocarbon dating at the Oxford Radiocarbon Accelerator Unit (ORAU). *Radiocarbon* 52:103–112.
- Bronk Ramsey C. 1995. Radiocarbon calibration and analysis of stratigraphy: the OxCal program. *Radiocarbon* 37: 425–430.
- Bronk Ramsey C. 2000. Comment on “The use of Bayesian statistics for <sup>14</sup>C dates of chronologically ordered samples: a critical analysis.” *Radiocarbon* 42: 199–202.
- Bronk Ramsey C. 2008. Radiocarbon Dating: Revolutions in Understanding. *Archaeometry* 50: 249–275.
- Bronk Ramsey C. 2009a. Dealing with outliers and offsets in radiocarbon dating. *Radiocarbon* 51:1023–1045.



- Bronk Ramsey C. 2009b. Bayesian analysis of radiocarbon dates. *Radiocarbon* 51: 337–360.
- Bronk Ramsey C. 2014a. OxCal v.4.2.4. Released 2014 May 9. Oxford Radiocarbon Accelerator Unit (ORAU). [accessed 2015 Jun 28]. <https://c14.arch.ox.ac.uk>
- Bronk Ramsey C. 2014b. Chronological Query Language (CQL2) Command Reference. OxCal Project.
- Buck CE, Cavanagh WG, Litton CD. 1996. Bayesian approach to interpreting archaeological data. Chichester, England: Wiley.
- Buck CE, Kenworthy JB, Litton CD, Smith AFM. 1991. Combining archaeological and radiocarbon information: a Bayesian approach to calibration. *Antiquity* 65: 808–821.
- Chapman A. 1957. Port of trade enclaves in Aztec and Maya civilizations. In: Polanyi K, Maynadier Arensberg C, Pearson HW, editors. *Trade and market in the early empires: Economies in history and theory*. Vol. 89. Glencoe: Free Press. p. 114–153.
- Closs MP. 1988. The Hieroglyphic Text of Stela 9, Lamanai, Belize. *Research Reports on Ancient Maya Writing*, #20:9-16. Washington, D.C.: Center for Maya Research.
- Contreras DA, Meadows J. 2014. Summed radiocarbon calibrations as a population proxy: a critical evaluation using a realistic simulation approach. *Journal of Archaeological Science* 52: 591–608.
- Culleton BJ. 2008. Crude demographic proxy reveals nothing about Paleoindian population. *PNAS* 105: E111.
- Culleton BJ, Prufer KM, Kennett DJ. 2012. A Bayesian AMS <sup>14</sup>C chronology of the Classic Maya Center of Uxbenká, Belize. *Journal of Archaeological Science* 39: 1572–1586.
- Dee M, Bronk Ramsey C. 2000. Refinement of graphite target production at ORAU. *Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms* 172:449–453.
- Dee M, Bronk Ramsey C. 2014. High-Precision Bayesian Modeling of Samples Susceptible to Inbuilt Age. *Radiocarbon* 56:83–94.
- Demarest AA, Rice PM, Rice DS. 2004. The Terminal Classic in the Maya Lowlands: Assessing Collapses, Terminations, and Transformations. In: Demarest AA, Rice PM, Rice DS, editors. *The Terminal Classic in the Maya Lowlands: Collapse, Transition, and Transformation*. Boulder: University Press of Colorado. p. 545–572.
- Douglas PMJ, Brenner M, Curtis JH. 2015. Methods and future directions for paleoclimatology in the Maya Lowlands. *Global and Planetary Change* (in press). [accessed 2015 Oct 22]. 10.1016/j.gloplacha.2015.07.008

- Ebert CE, Culleton BJ, Awe JJ, Kennett DJ. 2016. AMS 14C Dating of Preclassic to Classic Period Household Construction in the Ancient Maya Community of Cahal Pech, Belize. *Radiocarbon* 58:69–87.
- Ebert CE, Prufer KM, Macri MJ, Winterhalder B, Kennett DJ. 2014. Terminal Long Count Dates and the Disintegration Of Classic Period Maya Polities. *Ancient Mesoamerica* 25:337–356.
- Flint RF, Deevey ES. 1962. Editorial Statement. *Radiocarbon* 4: v.–vi.
- Godwin H. 1962. Radiocarbon Dating: Fifth International Conference. *Nature* 195: 943–945.
- Graham E. 1987. Terminal classic to historic-period vessel forms from Belize. In: Rice PM, Sharer RJ, editors. *Maya ceramics: papers from the 1985 Maya Ceramic Conference*. Oxford, England: B.A.R. p. 73–98.
- Graham E. 2004. Lamanai reloaded: alive and well in the Early Postclassic. In: *Research Reports in Belizean Archaeology: Papers of the 2004 Belize Archaeology Symposium*. Vol. 1. Belmopan, Belize: Institute of Archaeology, NICH. p. 223–241.
- Graham E. 2007. Lamanai, Belize from Collapse to Conquest -- Radiocarbon dates from Lamanai. Paper presented at the 106th Meeting of the AAA, Washington, D.C.
- Graham E. 2008. Lamanai Historic Monuments Conservation Project: Recording and Consolidation of New Church Architectural Features at Lamanai, Belize. Crystal River: Foundation for the Advancement of Mesoamerican Studies, Inc. (FAMSI).
- Graham E. 2011. *Maya Christians and their churches in sixteenth-century Belize*. Gainesville, FL: University Press of Florida.
- Graham E, Pendergast DM, Jones GD. 1989. On the Fringes of Conquest: Maya-Spanish Contact in Colonial Belize. *Science* 246: 1254.
- Grube N, Martin S, editors. 2004. *The Proceedings of the Maya Hieroglyphic Workshop—Patronage, Betrayal, and Revenge Diplomacy and Politics in The Eastern Maya Lowlands (The Maya Meetings at Texas, March 13-14, 2004)*. University of Texas at Austin.
- Guderjan TH, Garber J eds. 1995. *Maya maritime trade, settlement, and populations on Ambergris Caye, Belize*. San Antonio, Texas: Maya Research Program.
- Hammond N, Bobo MR. 1994. Pilgrimage's Last Mile: Late Maya Monument Veneration at La Milpa, Belize. *World Archaeology* 26: 19–34.
- Hammond N, Tourtellot G. 2004. Out with a whimper: La Milpa in the Terminal Classic. In: Demarest AA, Rice PM, Rice DS, editors. *The Terminal Classic in the Maya Lowlands: Collapse, Transition, and Transformation*. Boulder: University Press of Colorado. p. 288–301.

- Haug GH, Hughen KA, Sigman DM, Peterson LC, Rohl U. 2001. Southward migration of the intertropical convergence zone through the Holocene. *Science* 293: 1304–8.
- Hodell DA, Brenner M, Curtis JH. 2005. Terminal Classic drought in the northern Maya lowlands inferred from multiple sediment cores in Lake Chichancanab (Mexico). *Quaternary Science Reviews* 24: 1413–1427.
- Hoggarth JA, Culleton BJ, Awe JJ, Kennett DJ. 2014. Questioning Postclassic Continuity at Baking Pot, Belize, Using Direct AMS <sup>14</sup>C Dating of Human Burials. *Radiocarbon* 56: 1057–1075.
- Hoggarth JA, Breitenbach SFM, Culleton BJ, Ebert CE, Masson MA, Kennett DJ. 2015. The political collapse of Chichén Itzá in climatic and cultural context. *Global and Planetary Change* (in press) [accessed 2015 Dec 17 ]. DOI:110.1016/j.gloplacha.2015.12.007
- Honea K. 1975. Prehistoric Remains on the Island of Kythnos. *American Journal of Archaeology* 79: 277.
- Howie LA. 2005. Ceramic production and consumption in the Maya lowlands during the classic to postclassic transition: a technological study of ceramics at Lamanai, Belize. [PhD. Dissertation]. [Sheffield, UK]: The University of Sheffield.
- Howie LA. 2012. Ceramic change and the Maya collapse: a study of pottery technology, manufacture and consumption at Lamanai, Belize. BAR International Series, #2373. Oxford: Archaeopress.
- Huster AC, Smith ME. 2015. A New Archaeological Chronology for Aztec-Period Calixtlahuaca, Mexico. *Latin American Antiquity* 26:3–25.
- Inomata T, Ortiz R, Arroyo B, Robinson EJ. 2014. Chronological Revision of Preclassic Kaminaljuyú, Guatemala: Implications for Social Processes in the Southern Maya Area. *Latin American Antiquity* 25:377–408.
- Inomata T, Triadan D, Aoyama K, Castillo V, Yonenobu H. 2013. Early ceremonial constructions at Ceibal, Guatemala, and the origins of lowland Maya civilization. *Science* 340:467–471.
- Kennett DJ, Breitenbach SFM, Aquino VV, Asmerom Y, Awe J, Baldini JUL, Bartlein P, Culleton BJ, Ebert C, Jazwa C, et al. 2012. Development and Disintegration of Maya Political Systems in Response to Climate Change. *Science* 338: 788–791.
- Kennett DJ, Culleton BJ, Dexter J, Mensing SA, Thomas DH. 2014. High-precision AMS <sup>14</sup>C chronology for Gatecliff Shelter, Nevada. *Journal of Archaeological Science* 52:621–632.
- Kennett DJ, Culleton BJ, Voorhies B, Southon JR. 2011. Bayesian Analysis of High-Precision AMS <sup>14</sup>C Dates from a Prehistoric Mexican Shellmound. *Radiocarbon* 53:245–259.

- Kennett DJ, Hajdas I, Culleton BJ, Belmecheri S, Martin S, Neff H, Awe J, Graham HV, Freeman KH, Newsom L, et al. 2013. Correlating the Ancient Maya and Modern European Calendars with High-Precision AMS  $^{14}\text{C}$  Dating. *Scientific Reports* 3:1597.
- Kennett, DJ, Hoggarth JA, Culleton BJ. 2015. Examining the Disintegration of Maya Polities and Demographic Decline in the Central Maya Lowlands. Grant proposal funded by the National Science Foundation (BCS-1460369, \$103,058, 2015-2016).
- Kennett DJ, Ingram BL, Southon JR, Wise K. 2002. Differences in  $^{14}\text{C}$  Age Between Stratigraphically Associated Charcoal and Marine Shell from the Archaic Period Site of Kilometer 4, Southern Peru: Old Wood or Old Water? *Radiocarbon* 44: 53–58.
- King EM ed. 2015. *The Ancient Maya Marketplace: The Archaeology of Transient Space*. Tucson: University of Arizona Press.
- Krueger HW, Weeks CF. 1965. Geochron Laboratories, Inc. Radiocarbon measurements I. *Radiocarbon* 7: 47–53.
- Krueger HW, Weeks CF. 1966. Geochron Laboratories, Inc. Radiocarbon measurements II. *Radiocarbon* 8: 142–160.
- Lee S, Bronk Ramsey C. 2012. Development and Application of the Trapezoidal Model for Archaeological Chronologies. *Radiocarbon* 54:107–122.
- Lee S, Ramsey CB, Mazar A. 2013. Iron Age Chronology in Israel: Results from Modeling with a Trapezoidal Bayesian Framework. *Radiocarbon* 55:731–740.
- Lentz DL, Yaeger J, Robin C, Ashmore W. 2005. Pine, prestige and politics of the Late Classic Maya at Xunantunich, Belize. *Antiquity* 79:573–585.
- Loten HS. 2006. A Distinctive Maya Architectural Format: The Lamanai Temple. In: Andrews AP, Pendergast D, editors. *Reconstructing the past: studies in Mesoamerican and Central American Prehistory*. BAR International Series, #1529. Oxford: John and Erica Hedges. p. 89–106.
- Masson MA. 2002. Community Economy and the Mercantile Transformation in Postclassic Northeastern Belize. In: Freidel DA, Masson MA, editors. *Ancient Maya Political Economies*. Walnut Creek: AltaMira Press. p. 335–364.
- Masson MA, Freidel DA. 2012. An Argument for Classic Era Maya Market Exchange. *Journal of Anthropological Archaeology* 31: 455–484.
- Masson MA, Freidel DA. 2013. Wide Open Spaces: A Long View of the Importance of Maya Market Exchange. In: Hirth KG, Pillsbury J, editors. *Merchants, markets, and exchange in the Pre-Columbian world*. Washington, DC: Dumbarton Oaks Research Library and Collection. p. 201–228.

- Masson MA, Mock SB. 2004. Ceramics and settlement patterns at Terminal Classic-period lagoon sites in northeastern Belize. In: Demarest AA, Rice PM, Rice DS, editors. *The Terminal Classic in the Maya Lowlands: Collapse, Transition, and Transformation*. Boulder: University Press of Colorado. p. 367–401.
- Mayfield, T., 2015. *Historical-Archaeological Analysis of The Nineteenth-Century British Plantation Settlement At Lamanai, Belize (1837-1868)*. Ph.D. dissertation. University of Arizona Department of Anthropology, Tucson.
- McAnany PA. 1989. Economic Foundations of Prehistoric Maya Society; Paradigms and Concepts. In: McAnany PA, Isaac BL, editors. *Prehistoric Maya economies of Belize*. Greenwich, Conn.: JAI Press. p. 347–372.
- McKillop H. 1996. Ancient Maya trading ports and the integration of long-distance and regional economies: Wild Cane Cay in south-coastal Belize. *Ancient Mesoamerica* 7: 49–62.
- Metcalfe S, Breen A, Murray M, Furley P, Fallick A, McKenzie A. 2009. Environmental change in northern Belize since the latest Pleistocene. *J. Quaternary Sci.* 24: 627–641.
- Morehart CT, Lentz DL, Prufer KM. 2005. Wood of the Gods: The Ritual Use of Pine (*Pinus* spp.) by the Ancient Lowland Maya. *Latin American Antiquity* 16:255–274.
- Mueller AD, Islebe GA, Anselmetti FS, Ariztegui D, Brenner M, Hodell DA, Hajdas I, Hamann Y, Haug GH, Kennett DJ. 2010. Recovery of the forest ecosystem in the tropical lowlands of northern Guatemala after disintegration of Classic Maya polities. *Geology* 38: 523–526.
- Nelson C. 1980. The Elmenteitan lithic industry. In: *Pan-African Congress on Prehistory and Quaternary Studies*, Leakey RE, Ogot BA, editors. *Proceedings of the 8th Panafrican Congress of Prehistory and Quaternary Studies: Nairobi, 5 to 10 September, 1977*. Nairobi: International Louis Leakey Memorial Institute for African Prehistory.
- Olsson IU. 1970. The Use of Oxalic Acid as a Standard. In: *Radiocarbon Variations and Absolute Chronology: Proceedings of the 12th Nobel Symposium*, Uppsala University. New York: Wiley Interscience Division. p. 12.
- ORAU website. 2015 Oct 22. *Methods: Oxford Radiocarbon Accelerator Unit*. [accessed 2015 Nov 4]. <https://c14.arch.ox.ac.uk/methods.html>
- Overholtzer L. 2014. A New Bayesian Chronology for Postclassic and Colonial Occupation at Xaltocan, Mexico. *Radiocarbon* 56:1077–1092.
- Pendergast DM. 1981. Lamanai, Belize: Summary of excavation results, 1974–1980. *Journal of Field Archaeology* 8: 29–53.
- Pendergast DM. 1982a. Lamanai, Belice, durante el Posclásico. *Estudios de Cultura Maya* 14: 19–58.



- Pendergast DM. 1982b. Ottawa, Stella Dallas, and the Woodlice. *Archaeological Newsletter of the Royal Ontario Museum (ROM) New Series*, #203, Toronto.
- Pendergast DM. 1985. Lamanai, Belize: an updated view. In: Chase AF, Rice PM, editors. *The Lowland Maya Postclassic*, University of Texas Press, Austin. p. 91–103.
- Pendergast DM. 1986. Stability through change: Lamanai, Belize, from the ninth to the seventeenth century. In: Sabloff JA, Andrews V EW, editors. *Late Lowland Maya Civilization: Classic to Postclassic*. Albuquerque: School of American Research, University of New Mexico Press. p. 223–249.
- Pendergast DM. 1988. Lamanai Stela 9: The Archaeological Context. *Research Reports on Ancient Maya Writing*, #20:1-8. Washington, D.C.: Center for Maya Research.
- Pendergast DM. 1990. Up from the dust: the central lowlands Postclassic as seen from Lamanai and Marco González, Belize. In: Clancy FS, Harrison PD, editors. *Vision and Revision in Maya Studies*. Albuquerque: University of New Mexico Press. p. 169–177.
- Pendergast DM. 1998. Intercession with the gods: Caches and their significance at Altun Ha and Lamanai, Belize. Mock SB, editor. *The Sowing and the Dawning: Termination, Dedication, and Transformation in the Archaeological and Ethnographic Record of Mesoamerica*, University of New Mexico Press, Albuquerque: 55–63.
- Pendergast DM. 2000. The Problems Raised by Small Charcoal Samples for Radiocarbon Analysis. *Journal of Field Archaeology* 27: 237–239.
- Pendergast DM. 2006. Patterns of cache composition and placement at Lamanai, Belize. In: Andrews AP, Pendergast D, editors. *Reconstructing the past: studies in Mesoamerican and Central American Prehistory*. BAR International Series, #1529. Oxford: John and Erica Hedges. p. 59–70.
- Phillipson DW. 1977. The excavation of Gobedra rock-shelter, Axum: an early occurrence of cultivated finger millet in northern Ethiopia. *AZANIA: Journal of the British Institute in Eastern Africa* 12: 53–82.
- Powis TG. 2002. *An integrative approach to the analysis of the late Preclassic ceramics at Lamanai, Belize [PhD. Dissertation]*. Austin: The University of Texas.
- Powis T, Mazzullo SJ, Graham E. 2009. An Archaeological and Geological Assessment of a Presumed Ancient Maya Harbour at Lamanai, Belize. In: Morris J, Jones S, Awe J, Thompson G, Helmke C, editors. *Archaeological investigations in the eastern Maya lowlands: papers of the 2008 Belize Archaeology Symposium*. Vol. 6. Belmopan, Belize: Institute of Archaeology, National Institute of Culture and History. p. 252–262.
- Prufer KM, Dunham PS. 2009. A shaman's burial from an Early Classic cave in the Maya Mountains of Belize, Central America. *World Archaeology* 41:295–320.

- Reimer PJ, Bard E, Bayliss A, Beck JW, Blackwell PG, Ramsey CB, Buck CE, Cheng H, Edwards RL, Friedrich M. 2013. IntCal13 and Marine13 radiocarbon age calibration curves 0–50,000 years cal BP. *Radiocarbon* 55: 1869–1887.
- Rice PM, Forsyth DW. 2004. Terminal Classic-period lowland ceramics. In: Demarest A, Rice DS, editors. *The Terminal Classic in the Maya lowlands: collapse, transition, and transformation*. Boulder: University Press of Colorado. p. 28–59.
- Robichaux HR, Houk, Brett A. 2005. A Hieroglyphic Plate Fragment from Dos Hombres, Belize: Epigraphic and Archaeological Evidence Relating to Political Organization in the Three Rivers Region of Northwestern Belize and Northeastern Guatemala. Valdez Jr F, Meadows R, Houk BA, editors. *Mono y Conejo: Journal of the Mesoamerican Archaeological Research Lab, The University of Texas at Austin* 3:4–12.
- Robinson ME, McKillop HI. 2013. Ancient Maya wood selection and forest exploitation: a view from the Paynes Creek salt works, Belize. *Journal of Archaeological Science* 40:3584–3595.
- Robinson WS. 1951. A Method for Chronologically Ordering Archaeological Deposits. *American Antiquity* 16:293.
- Rushton EA, Metcalfe SE, Whitney BS. 2013. A late-Holocene vegetation history from the Maya lowlands, Lamanai, Northern Belize. *The Holocene* 23: 485–493.
- Sabloff JA; Henderson JS, editors. 1993. *Lowland Maya civilization in the eighth century A.D.: a symposium at Dumbarton Oaks, 7th and 8th October 1989*. Washington, D.C.: Dumbarton Oaks Research Library and Collection.
- Sabloff JA, Rathje WL. 1975. The Rise Of The Maya Merchant Class. *Scientific American* 233: 72–82.
- Schiffer MB. 1986. Radiocarbon dating and the “old wood” problem: The case of the Hohokam chronology. *Journal of Archaeological Science* 13: 13–30.
- Simmons SE, Pendergast DM, Graham E. 2009. The context and significance of copper artifacts in Postclassic and Early Historic Lamanai, Belize. *Journal of Field Archaeology* 34:57–75.
- Staff R, Reynard L, Brock F, Bronk Ramsey C. 2014. Wood Pretreatment Protocols and Measurement of Tree-Ring Standards at the Oxford Radiocarbon Accelerator Unit (ORAU). *Radiocarbon* 56:709–715.
- Steier P, Rom W. 2000. The use of Bayesian statistics for  $^{14}\text{C}$  dates of chronologically ordered samples: a critical analysis. *Radiocarbon* 42: 183–198.
- Stuiver M, Polach HA. 1977. Discussion; reporting of C-14 data. *Radiocarbon* 19: 355–363.
- Stuiver M, Reimer PJ. 2015 Nov 4. Isotope Fractionation Calculations. CALIB  $^{14}\text{C}$  Calibration Program, v.7.1. [accessed 2015 Nov 4]. <http://calib.qub.ac.uk/calib/fractionation.html>

- Sullivan LA, Sagebiel KL. 2003. Changing Political Alliances in the Three Rivers Region. In: Valdez Jr. F, Scarborough VL, editors. Heterarchy, political economy, and the ancient Maya: the Three Rivers Region of the east-central Yucatán Peninsula. p. 25–36.
- Sullivan LA, Houk BA, Valdez Jr F. 2007. The Terminal Classic In The Three Rivers Region. Research Reports in Belizean Archaeology, Institute of Archaeology, NICH, Belize. 4:135–146.
- Taylor RE, Bar-Yosef O. 2014. Radiocarbon Dating, Second Edition: An Archaeological Perspective. 2nd ed. Walnut Creek, CA: Left Coast Press.
- Ting KC. 2013. Change, continuity, and the Maya collapse: reconstructing the ceramic economy in the Eastern Maya Lowlands during the classic to postclassic transition [PhD. Dissertation]. Institute of Archaeology, University College London.
- Thompson JE. 1930. Ethnology Of The Mayas of Southern and Central British Honduras. Publications of the Field Museum of Natural History. Anthropological Series 17:27–213
- Vogt EZ. 1981. Some aspects of sacred geography of Highland Chiapas. In: Benson EP, editor. Mesoamerican Sites and World-Views: A Conference at Dumbarton Oaks, October 16th and 17th, 1976. Washington, D.C.: Dumbarton Oaks Research Library and Collection. p. 119–143.
- Walker DS. 1990. Cerros revisited: Ceramic indicators of Terminal Classic and Postclassic settlement and pilgrimage in northern Belize [PhD. Dissertation]. Dallas: Southern Methodist University.
- Ward GK, Wilson SR. 1978. Procedures for Comparing and Combining Radiocarbon Age Determinations: A Critique. Archaeometry 20:19–31.
- Webster DL. 2002. The Fall of the Ancient Maya: Solving the mystery of the Maya collapse. New York: Thames & Hudson.
- Williams AN. 2012. The use of summed radiocarbon probability distributions in archaeology: a review of methods. Journal of Archaeological Science 39: 578–589.
- Wrobel G, Graham EA. 2015. The Buk Phase Burials of Belize: Testing Genetic Relatedness Among Early Postclassic Groups in Northern Belize Using Dental Morphology. In: Cucina A, editor. Archaeology and Bioarchaeology of Population Movement among the Prehispanic Maya. Cham: Springer International Publishing. p. 85–95.
- Zahid HJ, Robinson E, Kelly RL. 2016. Agriculture, population growth, and statistical analysis of the radiocarbon record. PNAS 113:931–935.

## Figure and Table Captions:

- [p3] **Figure 1:** Central Precinct of Lamanai (modified from Pendergast 1981)
- [p5] **Figure 2:** Plaza N10[3] (Ottawa Group), (from Graham 2004)
- [p7] **Table 1:** All Radiocarbon Dates from Lamanai (see Appendix I for complete information)
- [p10] **Figure 3:** Modeled Sequence for Structures N10-77/N10-12, Ottawa Group, Lamanai (colors in the online version correspond to samples used in Figure 4 ceramic sums)
- [p12] **Figure 4:** Samples Associated with Diagnostic Ceramics (colored in online version), with Trapezoidal Probability Distributions and Sum of All Samples in Background
- [p16] **Figure 5:** Modeled Sequence and Stratigraphy for Structure N10-2, Lamanai (colors in online version correspond to samples used in Figure 4 ceramic sums)
- [p19] **Figure 6:** Diagnostic ceramic markers for transition from the late Late Classic to early Terminal Classic to late Terminal Classic at Lamanai; photos of cache LA 1785
- [p22-24] **Appendix I:** Complete List of Radiocarbon Dates from Lamanai (grayed samples not in associated Bayesian model; outlined samples combined in model. In online version: gold samples are outliers; blue are final, modeled ranges)