

KEEPING THE SEA OUT: EARLY MEDIEVAL STRUCTURES AT CA' FOSCARI UNIVERSITY, VENICE, ITALY

John Meadows¹ • Nicoletta Martinelli² • Olivia Pignatelli² • Rossella Cester³ • Luigi Fozzati⁴ • Bernd Kromer⁵

ABSTRACT. In 2004, the courtyard of Ca' Foscari University, Venice, was excavated in advance of building work, revealing an unbroken sequence of archaeological deposits. The earliest layers consisted of redeposited natural sediment, packed into wattle structures, a system of land reclamation first described by Cassiodorus in AD 537–8, and now known from several other sites in the city. The ground level was built up and extended several times with successive wattle structures, before the eventual construction of a stone waterfront. We have used Bayesian modeling of dendrochronological, radiocarbon, and stratigraphic dating evidence to obtain a precise chronology for the earliest phases of occupation, and to compare it to the chronology of land reclamation at similar sites elsewhere in Venice.

INTRODUCTION

Islands in the Venetian lagoon were settled intensively in the 5th and 6th centuries AD, following the collapse of Roman authority on the mainland in the aftermath of barbarian invasions. Until the 9th century, settlements elsewhere in the lagoon (e.g. Torcello, Malamocco, San Francesco del Deserto) appear to have been more important than the site of Venice itself. The history of these early settlements is poorly documented, but a useful description is given in a letter written by Cassiodorus, a minister of the Ostrogoth king Witiges, to the Tribuni Maritimorum, officials responsible for their administration, in AD 537–8. Cassiodorus described the method used to reclaim land as the settlements grew: *Viminibus enim flexibilibus illigatis terrena illic soliditas aggregatur et marino fluctui tam fragilis munitio non dubitatur opponi* (“there the earth is consolidated with interwoven wattles, and such fragile structures are built confidently against the waves of the sea”). These flexible wooden structures (*volparoni*) were filled with sediment from adjacent sandbanks, simultaneously extending the land area, raising the ground level, and deepening surrounding channels.

This initial phase of consolidation was first recorded archaeologically at sites in the eastern lagoon (Canal 1998). In Venice itself, boreholes at San Lorenzo, near San Marco, produced several radiocarbon results on structural timbers indicating occupation in the 6th–7th century cal AD (Ammerman et al. 1992), but only in the last decade has it become feasible to excavate *volparoni* structures, during the mandatory installation of deep cisterns when major buildings (*palazzi*) are restored. *Volparoni* structures are often encountered at about 1.5 m below mean sea level, but their complete horizontal and vertical exposure has not been possible, because of the restrictive working conditions in rescue archaeology. One of the most extensive recent investigations is the excavation in the courtyard of Palazzo Ca' Foscari, the seat of the University of Venice, in 2004 (Figure 1).

¹Zentrum für Baltische und Skandinavische Archäologie, Schloss Gottorf, 24837 Schleswig, Germany; Leibniz-Labor für Altersbestimmung und Isotopenforschung, Christian-Albrechts-Universität zu Kiel, Max-Eyth-Str. 11–13, 24118 Kiel, Germany. Corresponding author. Email: jmeadows@leibniz.uni-kiel.de.

²Dendrodata s.a.s., via Cesiolo 18, Verona 37126, Italy.

³Studio Associato Bettinardi Cester Archeologi, S. Croce, 2259, Venezia 30135, Italy.

⁴Soprintendenza per i Beni Archeologici del Friuli Venezia Giulia, viale Miramare 9, 34135 Trieste, Italy.

⁵Heidelberger Akademie der Wissenschaften, c/o Institut für Umwelphysik, Universität Heidelberg, Im Neuenheimer Feld 229, 69120 Heidelberg, Germany.



Figure 1 Map of central Venice, Italy, showing locations of sites where *volparoni* structures have been dated: 1) Ca' Foscari; 2) Teatro Malibrán; 3) ex-Cinema San Marco. Inset: the 22-m-long excavated area (dashed line) in the courtyard of Palazzo Ca' Foscari. Based on a figure in Fozzati and Cester (2005).

SITE DESCRIPTION

Archaeological investigation at Ca' Foscari began in 2002, when 6 boreholes were drilled to a depth of 6 m below the courtyard surface, to determine the extent of anthropogenic deposits. Wooden structures were found at about 3 m depth, or ~ 1.5 m below present mean sea level, and a single ^{14}C sample confirmed the late antique/early Medieval date of this timber (Rome-1598, 1460 ± 50 BP, cal AD 470–660).

An area 22×5.5 m was excavated in the courtyard in 2004, to the permitted depth of 1.8 m below mean sea level, without reaching archaeologically sterile deposits. A stratigraphic sequence of 14 phases was distinguished, beginning with *volparoni* structures extending from the east to the center, with later deposits, including an infilled canal, at the western end of the trench (Fozzati and Cester 2005).

The earliest structures consisted of lines of wooden posts, with interwoven branches of various species (see below). Layers of sediment were dumped behind these *volparoni*, to raise and expand the area around what must have been a natural topographic high point. The dumped layers contain the foraminifer *Trochammina inflata*, characteristic of intertidal flats or sandbanks in the lagoon, suggesting that the sediment was obtained from partly submerged areas. Strand-lines of plant debris on the raised ground surface are related to the construction of a second phase of *volparoni*. This phase is more complex, including 2 episodes of consolidation and 2 occupation levels. The earlier series of structures follows the same north-south alignment of the first phase, while the second series forms an arc from north-east to north-west. Again, the occupation levels are rich in plant debris, including reed matting in the upper level (Figure 2). The occupation level for the third *volparoni* phase, whose structures include a probably temporary plank walkway, is about 1 m higher than the earliest recorded occupation level. These phases did not yield closely datable finds.

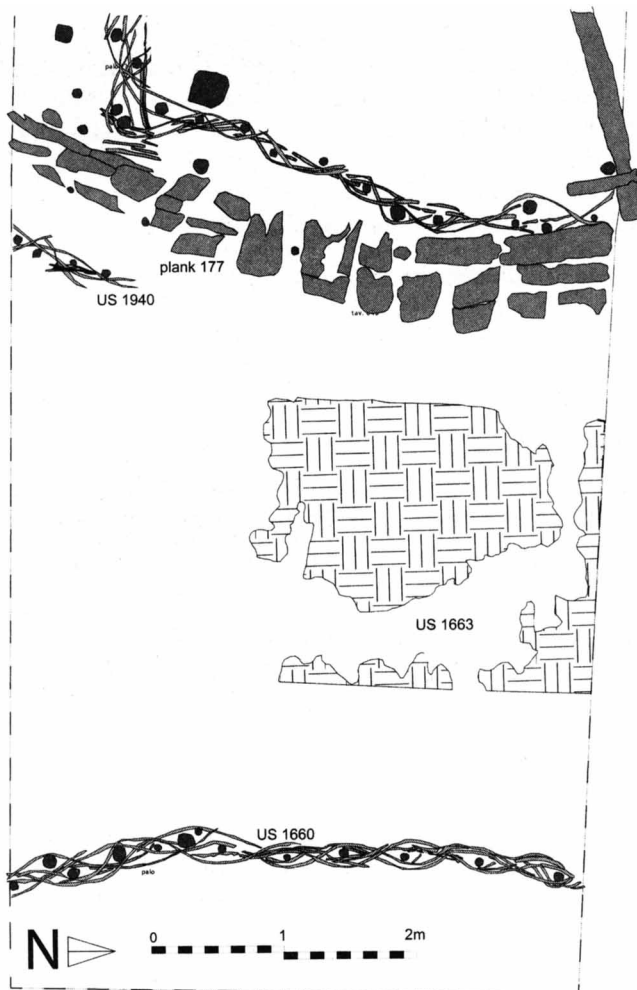


Figure 2 Plan of the eastern end of the Ca' Foscari courtyard trench, showing 3 of the *volparoni* structures, the timber walkway and reed matting (US 1663). Based on a figure in Fozzati and Cester (2005).

A fourth phase comprises a series of dumped layers and occupation levels, with artifacts ranging in date from Roman building materials to coarse pottery and amphorae of the 7th–8th centuries AD, and, from one of the occupation levels, ~0.2 m below modern mean sea level, a Byzantine coin struck in AD 518–522. In the next phase, these occupation levels were partly covered by natural sandy layers. The sixth phase is marked by the construction of a timber waterfront, downslope at 1.3 m below modern sea level. After several further layers accumulated both by natural processes and intentional deposition, a new waterfront was built, in stone. Only its base remains, but associated backfills and occupation levels suggest that it reached to at least 0.5 m below modern sea level. Later phases consist of a series of dumps of building rubble that filled in the associated canal, creating a level surface on which a timber building was raised in the 13th century. Since the 15th century, when Palazzo Ca' Foscari was built, the area has been an open courtyard.

MATERIALS AND METHODS

Scientific dating efforts were focussed on the initial phases of occupation, associated with *volparoni* and contemporary wooden structures. Six timbers were suitable for dendrochronological analysis, 10 were selected for ^{14}C dating, and a further 60 wood samples were selected for species identification. In all, 28 timbers were identified as deciduous oak (*Quercus* sp. sect. *Robur*), 19 as elm (*Ulmus* sp.), 14 as alder (*Alnus* sp.), 4 as hazel (*Corylus avellana* L.), 3 as hornbeam (*Carpinus betulus* L.), 3 as willow (*Salix* sp.), and 2 as *Pomoideae*. Single specimens of maple (*Acer* sp.), ash (*Fraxinus* sp.), and hophornbeam/hornbeam (*Ostrya/Carpinus*) were identified.

Six samples, from 1 post and 5 planks, were submitted to dendrochronological analysis. Three samples (the post, a vertical and a horizontal plank) were oak timbers, from the structures US 50, US 184, and US 1879 (Table 1). Elm (*Ulmus* sp.) timbers from structures US 177, US 186, and US 193 were also analyzed (Table 1). Unfortunately, almost all timbers in *volparoni* structures were rejected, either because the species concerned is unsuitable for dendrochronological analysis, or because the number of growth rings was inadequate.

Standard dendrochronological methods were followed (Fritts 1976; Baillie 1982). Tree rings were measured from pith to bark-edge using the LINTAB device (F Rinn, Heidelberg, Germany), to a precision of 0.01 mm. Data were recorded and processed using the software TSAP[®] (Rinntech 2003) and CATRAS[®] (Aniol 1983).

Table 1 Dendrochronological samples of Ca' Foscari. Cross-matching positions for the final ring in each sample are given relative to the 250-yr floating regional oak chronology for eastern Veneto (Martinelli and Kromer 2002).

Sample	Species	Rings	Center	Sap-wood	Bark-edge	Cross-match
plank US 1879	oak (<i>Quercus</i> sp. sect. <i>Robur</i>)	70	—	—	—	year 199
plank US 184	oak (<i>Quercus</i> sp. sect. <i>Robur</i>)	60	—	—	—	—
plank US 177	elm (<i>Ulmus</i> sp.)	95	—	—	uncertain	year 226
post US 50	oak (<i>Quercus</i> sp. sect. <i>Robur</i>)	90	—	—	—	—
plank US 186	elm (<i>Ulmus</i> sp.)	81	—	—	—	—
plank US 193	elm (<i>Ulmus</i> sp.)	41	—	—	—	—

A single ^{14}C sample (4-US8) of unidentified worked wood from the 2002 boreholes was dated to confirm that the structures located at 1.5–1.6 m below mean sea level were of early Medieval date. Following the 2004 excavation, 10 ^{14}C samples were selected from as many structures (wattles from the *volparoni* structures US 1660, US 1757A, US 1814, US 1871, US 1882, US 1940, US 2000, and

US 2121, and posts P226, P1292D; the last is from a later Medieval structure and is not discussed here). The outermost annual rings were sampled from each timber, which in every case was complete to the bark-edge. The number of annual rings in each ^{14}C sample was recorded (Table 2).

The 2002 sample was dated at the ^{14}C laboratory of the Istituto di Geologia Ambientale e Geoingegneria, Università "La Sapienza" di Roma. After manual inspection and cleaning, and acid-base-acid (HCl-NaOH-HCl) pretreatment, the sample was converted to benzene and measured by liquid scintillation counting, according to methods described by Calderoni and Petrone (1992). The 2004 samples were dated by gas proportional counting at the University of Heidelberg Radiocarbon Laboratory. The wood samples ($n = 11$) were milled and pretreated using an acid-base-acid (ABA) sequence with NaOH overnight, HCl, NaOH, and HCl for 1 hr each, all at 80 °C. The wood was combusted in a de Vries-type combustion system, and the CO_2 was purified. The samples were measured for 9–12 days in low-level gas counters (Kromer and Münnich 1992). The results reported in Table 2 are conventional ^{14}C ages (Stuiver and Polach 1977).

Table 2 ^{14}C results for Ca' Foscari. The calibrated ranges were obtained by the maximum intercept method (Stuiver and Reimer 1986), using the IntCal09 calibration curve (Reimer et al. 2009) and the program OxCal v 4.1 (Bronk Ramsey 2009).

Sample	Wood identification and intrinsic age	Lab code	$\delta^{13}\text{C}$ (‰)	^{14}C age (BP)	Calibrated date (95% confidence)
core 4-US 8	—	Rome-1598	—	1460 ± 50	cal AD 470–660
post P226	Oak (<i>Quercus</i> sp. sect. <i>Robur</i>), 9 annual rings with bark-edge	Hd-24668	-26.8	1262 ± 20	cal AD 675–780
post 1292D	Elm (<i>Ulmus</i> sp.), 6 annual rings with bark-edge	Hd-24670	-26.0	905 ± 17	cal AD 1040–1185
wattle US 1660	Hazel (<i>Corylus avellana</i>), 5 annual rings with bark-edge	Hd-24673	-29.0	1418 ± 17	cal AD 600–660
wattle US 2121	Oak (<i>Quercus</i> sp. sect. <i>Robur</i>), 6 annual rings with bark-edge	Hd-24683	-27.8	1293 ± 21	cal AD 660–775
wattle US 1814	Willow (<i>Salix</i> sp.), 3 annual rings with bark-edge	Hd-24684	-28.1	1321 ± 19	cal AD 655–765
wattle US 2000	Oak (<i>Quercus</i> sp. sect. <i>Robur</i>), 3 rings with bark-edge	Hd-24687	-26.9	1278 ± 21	cal AD 665–780
wattle US 1882	Hophornbeam/hornbeam (<i>Ostrya/Carpinus</i>), 6 annual rings with bark-edge	Hd-24688	-28.6	1283 ± 19	cal AD 665–775
wattle US 1940	Oak (<i>Quercus</i> sp. sect. <i>Robur</i>), 7 annual rings with bark-edge	Hd-24703	-28.6	1341 ± 17	cal AD 650–685
wattle US 1757A	Willow (<i>Salix</i> sp.), 5 annual rings with bark-edge	Hd-24704	-26.9	1270 ± 17	cal AD 670–780
wattle US 1871	Hazel (<i>Corylus avellana</i>), 3 annual rings with bark-edge	Hd-24706	-28.1	1297 ± 18	cal AD 660–775

DENDROCHRONOLOGICAL RESULTS

The tree-ring measurement sequences from the 3 oak samples do not cross-match each other. The individual sequences were therefore compared both to oak chronologies from other sites and regions, and to chronologies for other species. Absolutely dated reference chronologies for Italian oak in this period do not exist, but the validity of cross-matching between Italian oak series and

Swiss and German reference chronologies for the last 2 millennia has been documented (Corona 1989), even though further experimental evidence is required (Martinelli 1996). Cross-matching was therefore attempted against the following reference chronologies:

- the central-eastern German oak chronology (AD 960–1960) (Huber and Giertz-Siebenlist 1978);
- the central-western German oak chronology (AD 700–1964) (Hollstein 1980);
- the south-central German oak chronology (8480 BC–AD 2009) (Becker et al. 1985, Friedrich et al. 2004; M Friedrich, personal communication);
- the unpublished Swiss oak chronology (AD 924–1985) (P Gassmann, Neuchâtel Cantonal Museum Laboratory, personal communication).

The oak series were also compared to the alpine silver fir (*Abies alba* Mill.) chronology (AD 820–1961) (Becker and Giertz-Siebenlist 1970). None of these comparisons gave acceptable cross-matches.

The oak series were then compared to the floating regional oak chronology for early Medieval eastern Veneto (Martinelli and Kromer 2002) and to floating oak chronologies from other sites in Venice. One sample, the horizontal plank from structure US 1879, produced satisfactory visual and statistical cross-matches against the eastern Veneto chronology, when the final ring present on the sample corresponds to year 199 in the regional chronology, with the following cross-dating parameters: TBP (Baillie and Pilcher's *T* value) 7.6; TH (Hollstein's *T* value) = 6.6; CDI (Cross-Date Index) = 384; GLK (*Gleichläufigkeit*) = 77% (Rinntech 2003). As the plank consisted only of heartwood, the sapwood having been removed during timber conversion, a minimum of 11 yr must be added to this date to estimate the earliest possible felling of the tree concerned, following Corona (1970, 1974). Wiggle-match ¹⁴C dating of the regional chronology (Martinelli and Kromer 2002) indicates a felling date in the mid-7th century cal AD or later.

Although there are relatively few dendrochronological studies of elm (Guibal 1998), an early Medieval floating elm chronology has been developed for Venice (Martinelli and Kromer 2002). Elm was widely used for structures in the Venice lagoon (O Pignatelli, unpublished data) and is easily analyzed, hence the local elm chronology. Moreover, elm has often been shown to cross-match with oak from the same site (Lambert and Lavier 1991).

One of the elm samples, US 177, provided satisfactory visual and statistical cross-matches with the regional oak chronology for early Medieval eastern Veneto (TBP = 4.5; TH = 4.3; CDI = 141; GLK = 66%) and with the floating elm chronology from the ex-Cinema San Marco site in Venice (TBP = 4.5; TH = 4.6; CDI = 93; GLK = 66%), confirming the latter's cross-matching position with the regional oak chronology (see Martinelli and Kromer 2002). The final measured ring of US 177 corresponds to year 226 of the oak chronology.

BAYESIAN MODELING

The ¹⁴C results, once calibrated (Stuiver and Reimer 1993; Reimer et al. 2009), provide accurate estimates, expressed as probability distributions, of the calendar dates of tree rings in individual samples, and, with appropriate adjustment for the samples' intrinsic ages, for the felling dates of the timbers concerned. These probability distributions, which are referred to as *likelihoods* in Bayesian chronological models (Buck et al. 1996), are independent of each other.

Bayesian modeling allows us to combine likelihoods with *prior* information about the relative ages of structures, which here may be inferred from stratigraphic relationships, to obtain a more precise

probability distribution (*posterior density estimate*) for the date for each sample. Bayesian models can also incorporate other dating evidence, such as when a coin was minted, and estimate the dates of events not directly associated with individual samples, such as when a site was occupied or abandoned. Posterior density estimates are not independent of each other: they depend on all the dating information in a model, and may change if any component is altered (e.g. if another ^{14}C sample is dated). For this reason, they are conventionally given in *italics*.

It is not possible to show all the dated structures on a single plan or section drawing due to the complexity of the stratigraphy (Fozzati and Cester 2005), but stratigraphic relationships between dated structures can readily be represented in a Harris matrix (Figure 3). Our model includes 2 timbers (US 1879 and US 177) not dated directly by ^{14}C . These timbers cross-match the eastern Veneto oak chronology, so a probability distribution for the date of the final ring of each timber can be obtained from a ^{14}C wiggle-match for this chronology (Martinelli and Kromer 2002). This does not give 2 independent likelihoods, as the age difference between the last ring of each timber is known from their cross-matching positions. We have calculated a probability distribution for the final ring of US 1879 (Figure 4), and cross-referenced this distribution in the model, with appropriate offsets, to obtain felling dates for US 1879 and US 177.

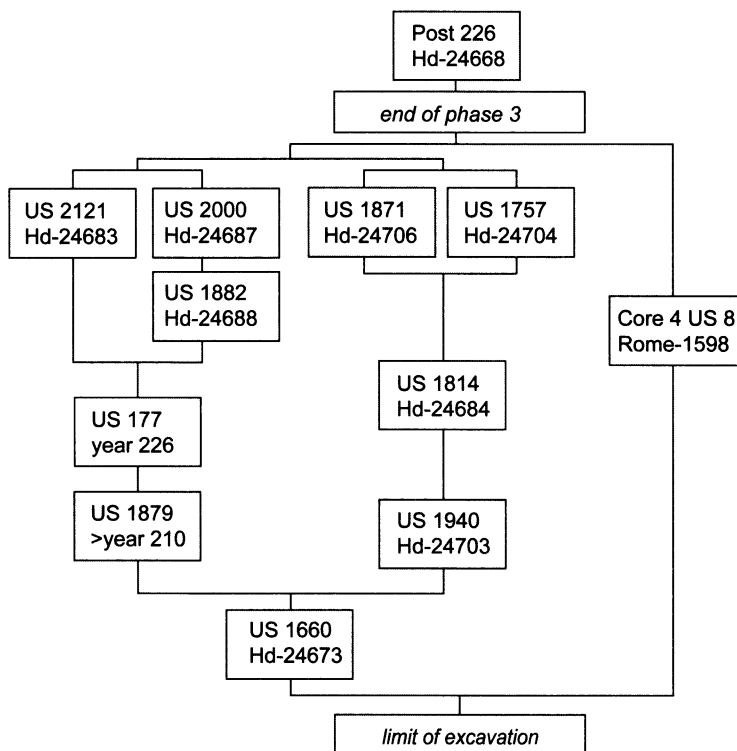


Figure 3 Harris matrix of dated samples, indicating the relative ages of timbers implicit in the stratigraphic relationships between structures. Aside from US 1879, each timber was complete to the bark edge. The outermost surviving ring of sample US 1879 was oak heartwood, dated to year 199 of the regional oak chronology, which implies that this timber was felled after year 210 (see text).

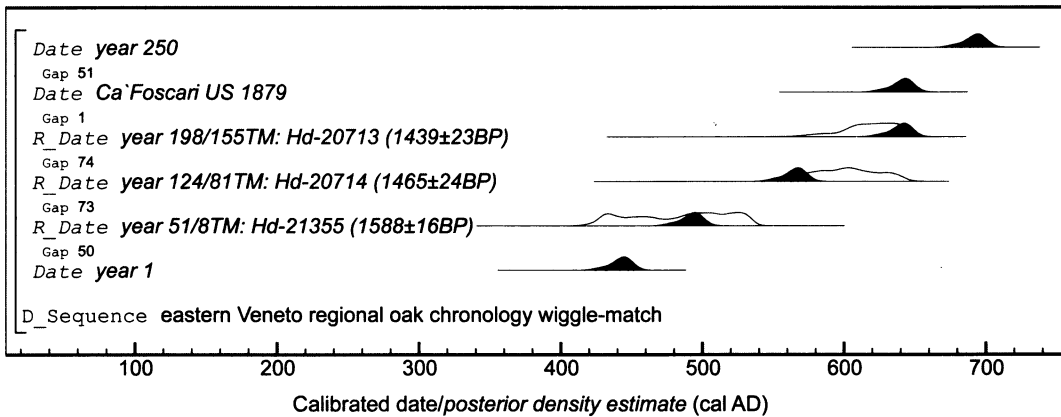


Figure 4 Wiggle-match for the eastern Veneto oak regional chronology, calculated using the *D_Sequence* function in OxCal v 4.1 ($A_{\text{comb}} = 73.3\%$, $A_n = 40.8\%$, $n = 3$; Bronk Ramsey et al. 2001), with an estimated date for the final ring of timber Ca' Foscari US 1879 (year 199 of the regional chronology).

The Bayesian model (Figure 5) has good “dynamic agreement” ($A_{\text{model}} > 60$: see Bronk Ramsey 2009), which indicates that the likelihoods are consistent with the relative dating of structures known from stratigraphy, and the implicit assumption that the structures were made of freshly felled wood. The posterior density estimates for individual samples are therefore interpreted as the construction dates of the relevant structures. The model also estimates the date of the *beginning* and *end* of this phase of occupation, and of the *First* and *Last* structure in this phase (Figure 5). Rome-1598, which is not associated with one of the stratified structures, fits within this phase of activity ($A > 60$: Bronk Ramsey 1995), and should not be interpreted as evidence of an earlier construction episode at Ca' Foscari. The posterior density estimate for the final ring of sample US 1879 (Figure 5, inset) is consistent with its likelihood, given by the regional chronology wiggle-match ($A = 109.7\%$: Bronk Ramsey 1995).

DISCUSSION

Our model estimates that the latest *volparoni* structure at Ca' Foscari was built in *cal AD* 690–770 or 695–730 (Figure 5: *Ca' Foscari Last*, 95% or 68% probability). This estimate is probably valid, as there was no evidence that these deposits had been truncated by later constructions, but the excavation did not reach natural soil, so the model's estimate of *cal AD* 610–665 (Figure 5: *Ca' Foscari First*, 95% probability) for the first structure may be regarded as a *terminus ante quem* for land reclamation at Ca' Foscari.

Volparoni structures have recently been excavated at several other sites in central Venice, including the Teatro Malibrán, near Rialto, and the ex-Cinema San Marco, near Piazza San Marco (Figure 1). The eastern Veneto oak chronology (Martinelli and Kromer 2002) is based mainly on planks from the Teatro Malibrán and ex-Cinema San Marco sites, which must therefore overlap in date with the *volparoni* phase at Ca' Foscari. Full stratigraphic sequences for these sites are not yet available, but a preliminary combined Bayesian model was created (Figure 6), incorporating the Ca' Foscari model and results from the ex-Cinema San Marco (Valle and Anglani, in press), where we simply assumed that all the dated timbers (whether dated by ^{14}C or dendrochronological cross-matching) represent a single “bounded” phase of activity (Bronk Ramsey 2000).

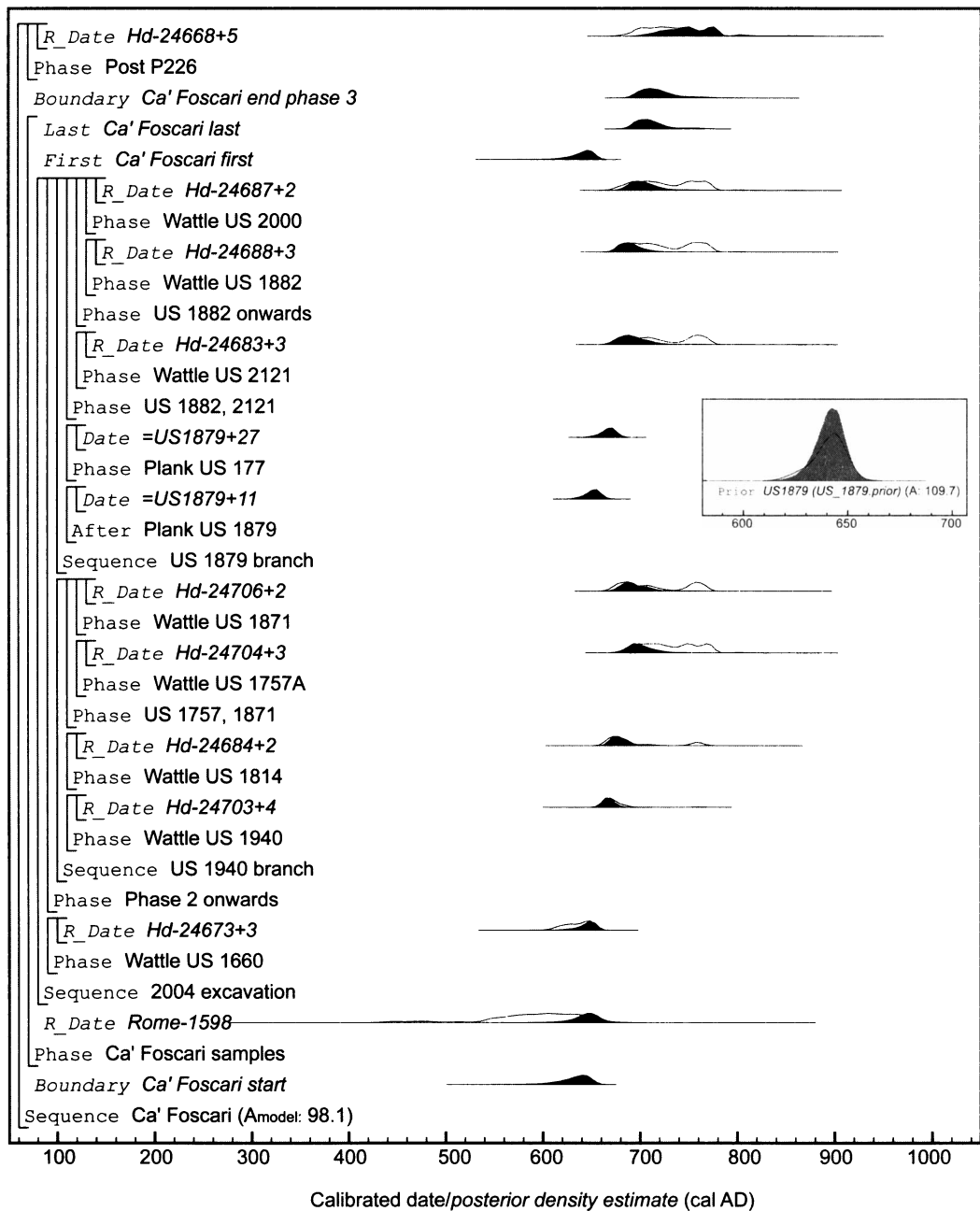


Figure 5 A Bayesian chronological model, implemented in OxCal v 4.1 (Bronk Ramsey 2009); the keywords and square brackets define the relative dating (shown in Figure 3) incorporated in the model. Distributions in outline are likelihoods for the felling dates of the timbers concerned, obtained by shifting the probability distribution of each calibrated ^{14}C result by half the number of annual rings in the sample (Table 2). The single likelihood associated with both Plank US 177 and Plank US 1879 is the distribution Ca' Foscari US 1879 (Figure 4). Solid distributions are posterior density estimates of the felling dates and associated events, including the final ring of US 1879 (inset). The satisfactory index of agreement ($A_{\text{model}} > 60$) indicates overall consistency between likelihoods and posterior density estimates.

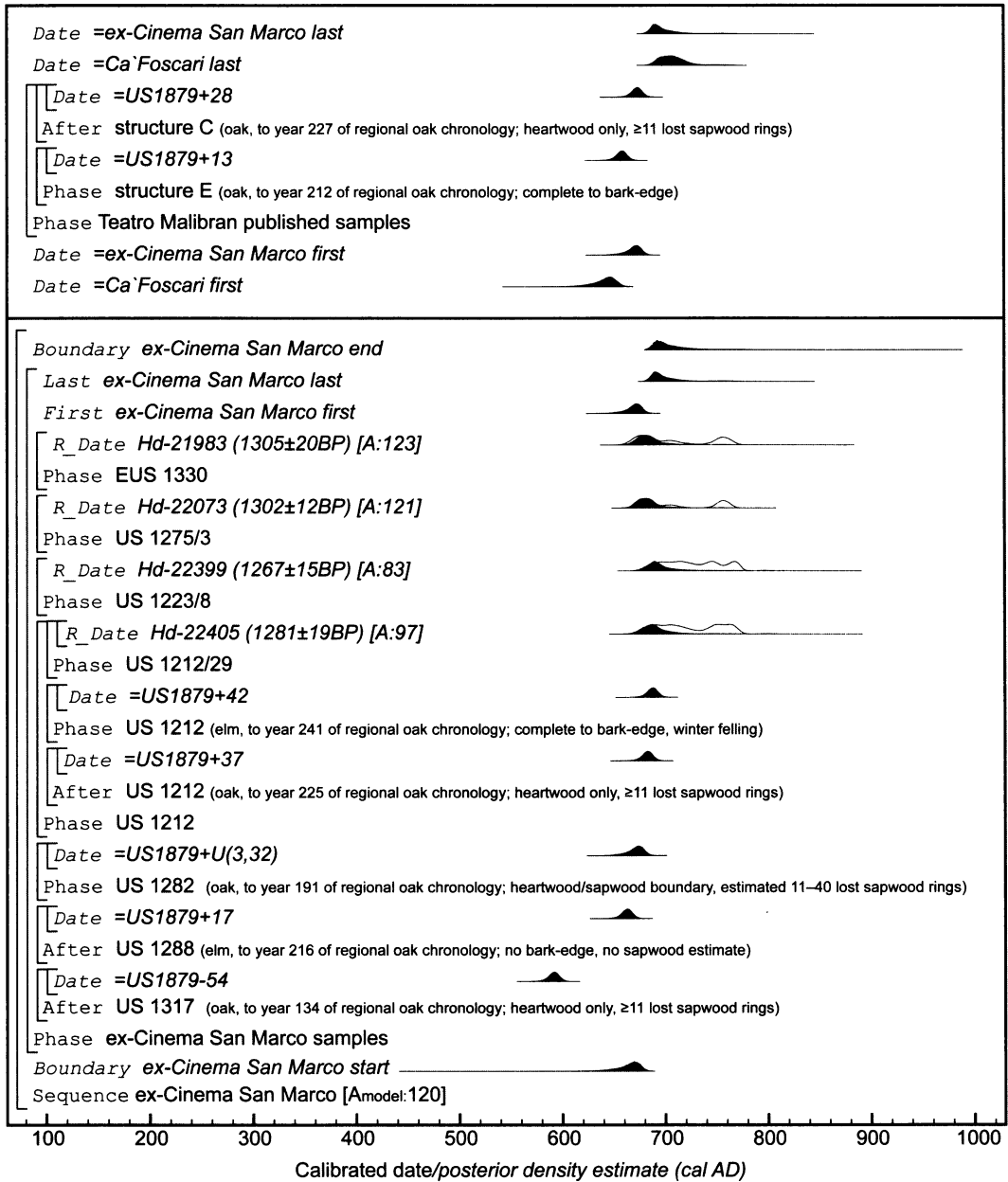


Figure 6 Combined chronological model, including data from Ca' Foscari and the ex-Cinema San Marco site (Valle and Anglani, in press). The likelihoods and structure of the Ca' Foscari section, not shown here, are identical to those in the model shown in Figure 5, but the posterior density estimates are slightly different, because the estimated date of US 1879 is also affected by the ex-Cinema San Marco results (shown in the lower panel). The upper panel shows the combined model's estimated dates of the first and last *volparoni* structures at Ca' Foscari and the ex-Cinema San Marco, and the dates of 2 structures at the Teatro Malibrán site, based on dendrochronological cross-matching (Martinelli and Kromer 2002) and the combined model's posterior density estimate for US 1879.

The combined model does not assume that there is any chronological relationship between the sites, other than the known dendrochronological cross-matches between some timbers. The model cross-references the dates of cross-matched timbers from the ex-Cinema San Marco to that of the final ring of sample US 1879 from Ca' Foscari, with offsets corresponding to the cross-matching positions. The posterior density estimate for US 1879 is therefore affected by ^{14}C results from both sites. In the original wiggle-match (Martinelli and Kromer 2002), year 250 of the eastern Veneto regional oak chronology was dated to cal AD 699 ± 21 (2σ), which would date the outermost surviving ring of US 1879 (year 199 of the regional oak chronology) to cal AD 648 ± 21 (2σ). In our combined model, US 1879 is dated to cal AD 634–657 (95% probability) or cal AD 646 ± 11 (2σ , Figure 7).

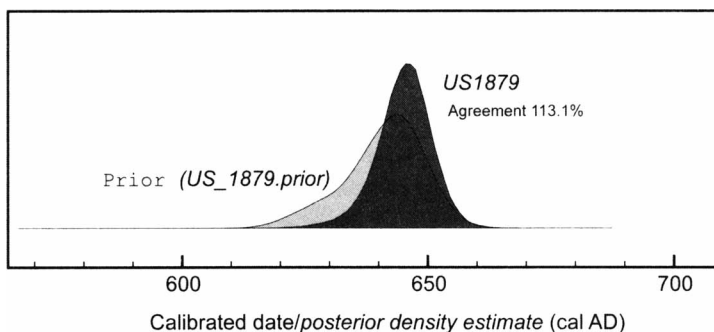


Figure 7 Estimated date of the final ring of sample US 1879. The outline distribution is derived from the model shown in Figure 4; the solid distribution is the posterior density estimate of the date of the same ring, based on the model shown in Figure 6.

The *First* and *Last* dates for each site estimated by the combined model bracket the dates of structures at the Teatro Malibrán based on dendrochronological cross-matching (Martinelli and Kromer 2002; in Figure 6, we have used the combined model's posterior density estimate, US 1879, with appropriate offsets, for the dates of these structures). Additional unpublished ^{14}C results from Teatro Malibrán support the interpretation that the 3 sites are almost exactly contemporaneous. The earliest *volparoni* structures at all 3 sites apparently date to the 7th century, but in each case excavations did not reach natural sediment, so the model estimates do not indicate the order in which these sites were developed. Nevertheless, the results show that land reclamation had begun in at least 3 areas of Venice by the later 7th century.

The last *volparoni* structure at Ca' Foscari and the ex-Cinema San Marco apparently dates to within decades of cal AD 700, which may imply a pause in the process of land reclamation in central Venice at the beginning of the 8th century. A possible explanation is the suggestion by Vito Favero that the sea level rose from 1.6 to 1.0 m below modern sea level between the 5th and 7th centuries, before falling back to 1.3 m below modern sea level in the 8th century (Tuzzato et al. 1993:78–80; chronology based on artifact attributions). There is some support for this idea at Ca' Foscari, where successive *volparoni* structures serve to raise the ground level, and subsequent waterfronts are slightly lower (see above). Although *volparoni* structures at the other sites are at similar depths with respect to modern sea level, precise altitudinal comparisons are difficult, as these levels have been compressed to some degree by later constructions; further work on this issue is required.

CONCLUSION

Recent excavations demonstrate the remarkable preservation of *volparoni* structures in Venice, whose survival may permit an accurate reconstruction of the early growth of the city, if archaeologists are able to take full advantage of the access provided by development activity. Historical evidence, such as church foundations, provide only a partial picture of the expansion of the early Medieval city, and then only from the 9th century onwards (Gelichi 2007). The Bayesian models presented here bring together the relative dating embodied in a complex stratigraphic sequence, calibrated dates from precise ^{14}C measurements of short-lived timbers from *volparoni* structures, and exact age differences known from dendrochronological analysis of larger timbers. The models show that at Ca' Foscari, on the bank of what would become the Grand Canal, an initial stage of land reclamation was already underway by the middle of the 7th century cal AD, and was completed by the early 8th century. At about the same time, land reclamation was also in progress 800 m to the east, at the ex-Cinema San Marco site, and 700 m further north, at the Teatro Malibran site. Whether Venice was already a large settlement by the late 7th century or whether these sites were just scattered islands remains to be discovered, but our results suggest that despite the scarcity of documentary evidence and closely datable artifacts in this period, a detailed chronology of the earliest structures can be realized by a consistent application of scientific dating methods and Bayesian modeling.

ACKNOWLEDGMENTS

We would like to thank the Ministero per i Beni e le Attività Culturali, Soprintendenza per i Beni Archeologici del Veneto, for permission to use Figures 1 and 2. The excavations and postexcavation analyses were funded by Università Ca' Foscari, Venezia.

REFERENCES

- Ammerman AJ, De Min M, Housley R. 1992. New evidence on the origins of Venice. *Antiquity* 66(253): 913–6.
- Aniol RW. 1983. Tree-ring analysis using CATRAS. *Dendrochronologia* 1:45–53.
- Baillie MGL. 1982. *Tree-Ring Dating and Archaeology*. London: Croom Helm.
- Becker B, Giertz-Siebenlist V. 1970. Eine über 1100 jährige mitteleuropäische Tannenchronologie. *Flora* 159: 310–46.
- Becker B, Billamboz A, Egger H, Gassmann P, Orcel A, Orcel C, Ruoff U, editors. 1985. *Dendrochronologie in der Ur- und Frühgeschichte: Die Absolute Datierung von Pfahlbausiedlungen Nördlich der Alpen im Jahrringkalender Mitteleuropas*. Basel: Verlag Schweizerische Gesellschaft für Ur- und Frühgeschichte.
- Bronk Ramsey C. 1995. Radiocarbon calibration and analysis of stratigraphy: the OxCal program. *Radiocarbon* 37(2):425–30.
- Bronk Ramsey C. 2000. Comment on 'The use of Bayesian statistics for ^{14}C dates of chronologically ordered samples: a critical analysis.' *Radiocarbon* 42(2):199–202.
- Bronk Ramsey C. 2009. Bayesian analysis of radiocarbon dates. *Radiocarbon* 51(1):337–60.
- Bronk Ramsey C, van der Plicht J, Weninger B. 2001. 'Wiggle matching' radiocarbon dates. *Radiocarbon* 43(2A):381–9.
- Buck CE, Cavanagh WG, Litton CD. 1996. *Bayesian Approach to Interpreting Archaeological Data*. Chichester: Wiley.
- Calderoni G, Petrone V. 1992. Department of Earth Sciences at the University of Rome radiocarbon dates I. *Radiocarbon* 34(1):105–13.
- Canal E. 1998. *Testimonianza Archeologiche nella Laguna di Venezia di Eta' Antica*. Cavallino di Venezia: Edizioni del Vento.
- Corona E. 1970. Cerchie dell'alburno in tronchi di rovere. *L'Italia Forestale e Montana* 25(3):156–8.
- Corona E. 1974. Ricostruzione dell'alburno in legnami sommersi. *Geoarcheologia* 1–2:19–22.
- Corona E. 1989. Significato dendrocronologico delle querce. *Monti e Boschi* 1:6–8.
- Fozzati L, Cester R. 2005. L'archeologia d'emergenza nelle operazioni di restauro: cronaca del cantiere di Cà Foscari. In: Pilo GM, De Rossi L, Alessandri D, Zuanier F, editors. *Ca' Foscari. Storia e Restauro del Palazzo dell'Università di Venezia*. Venice: Marsilio Editori. p 188–200.
- Friedrich M, Remmele S, Kromer B, Hofmann J, Spurk M, Kaiser KF, Orcel Ch, Küppers M. 2004. The 12,460-year Hohenheim oak and pine tree-ring chronology from central Europe—a unique annual record

- for radiocarbon calibration and paleoenvironment reconstructions. *Radiocarbon* 46(3):1111–22.
- Fritts HC. 1976. *Tree Rings and Climate*. New York: Academic Press.
- Gelichi S. 2007. Flourishing places in North-Eastern Italy: towns and *emporia* between late antiquity and the Carolingian age. In: Henning J, editor. *Post-Roman Towns, Trade and Settlement in Europe and Byzantium. Volume 1: The Heirs of the Roman West*. Berlin: Walter de Gruyter. p 77–104.
- Guibal F. 1998. Dendrocronologie et dendromorphologie. In: Volpe G, editor. *Archeologia Subacquea. Come Opera l'Archeologo. Storie delle Acque. VIII Ciclo di Lezioni sulla Ricerca applicata in Archeologia*. Florence: Edizioni all'Insegna del Giglio. p 425–46.
- Hollstein E. 1980. *Mitteuropäische Eichenchronologie*. Trier Grabungen und Forschungen 11.
- Huber B, Giertz-Siebenlist V. 1978 Our 1000-year oak annual-ring chronology. In: Fletcher J, editor. *Dendrochronology in Europe. Principles, Interpretations and Applications to Archaeology and History*. Oxford: British Archaeological Reports, International Series 51. p 27–32.
- Kromer B, Münnich KO. 1992. CO₂ gas proportional counting in radiocarbon dating – review and perspective. In: Taylor RE, Long A, Kra RS, editors. *Radiocarbon After Four Decades: An Interdisciplinary Perspective*. New York: Springer. p 184–97.
- Lambert G-N, Lavier C. 1983. Sciences et archéologie: application de la dendrocronologie a l'archéologie. *Bulletin de la Société d'Histoire Naturelle du Doubs* 81:63–87.
- Martinelli N. 1996. Datazioni dendrocronologiche per l'età del Bronzo dell'area alpina. In: Randsborg K, editor. *Absolute Chronology: Archaeological Europe 2500-500 B.C.* Acta Archaeologica, 67, Acta Archaeologica Supplementa I. p 315–26.
- Martinelli N, Kromer B. 2002. A new oak chronology for early medieval times in the Veneto region. In: D'Amico C, editor. *Atti del Secondo Congresso Nazionale di Archeometria*. Bologna. p 293–304.
- Reimer PJ, Baillie MGL, Bard E, Bayliss A, Beck JW, Blackwell PG, Bronk Ramsey C, Buck CE, Burr GS, Edwards RL, Friedrich M, Grootes PM, Guilderson TP, Hajdas I, Heaton TJ, Hogg AG, Hughen KA, Kaiser KF, Kromer B, McCormac FG, Manning SW, Reimer RW, Richards DA, Southon JR, Talamo S, Turney CSM, van der Plicht J, Weyhenmeyer CE. 2009. IntCal09 and Marine09 radiocarbon age calibration curves, 0–50,000 years cal BP. *Radiocarbon* 51(4): 1111–50.
- Rinntech. 2003. TSAP-Win™. Time series analysis and presentation for dendrochronology and related applications. Version 0.59 for Microsoft Windows 98, 2000, XP. User Reference. Heidelberg: Rinntech.
- Stuiver M, Polach HA. 1977. Discussion: reporting of ¹⁴C data. *Radiocarbon* 19(3):355–63.
- Stuiver M, Reimer PJ. 1986. A computer program for radiocarbon age calculation. *Radiocarbon* 28(2B): 1022–30.
- Stuiver M, Reimer PJ. 1993. Extended ¹⁴C data base and revised CALIB 3.0 ¹⁴C age calibration program. *Radiocarbon* 35(1):215–30.
- Tuzzato S, Favaro V, Vinals MJ. 1993. Venezia. San Pietro di Castello a Venezia. Nota preliminare dopo la campagna 1992. *Quaderni di Archeologia del Veneto* IX:72–80.
- Valle G, Anglani L. In press. Venezia ex-cinema San Marco. Le fasi medievali. In: *I Vasai del Leone: Ceramiche nel Veneto e del Veneto tra VI e XVI secolo*. Atti del Convegno Internazionale, Venice, 13–15 April 2004.