Tree-Rings, Kings, and Old World Archaeology and Environment:

Papers Presented in Honor of Peter Ian Kuniholm

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few centimeter thick border line between the soil and the pumice. This erosion precursor formed up to 7cm thick layer of fine volcanic dust. (Figure 2) on the southern part of Thera. The olive leaves imprints are found right inside the dust layer—not under it—which means that a hot cloud of volcanic dust enveloped the olive tree and made its leaves fall to the ground. We also find the fine dust layer on the upper surface of the cylindrical tunnels (molds) that have enveloped the branches. This dust had clearly fallen on the upper side of the branches of the standing tree and now shows the imprints of the bark, typical of olive trees. Even after extensive search in the neighborhood, we found the leaves only in the immediate neighborhood of the tree, indicating that they are unlikely to have originated from hypothetical nearby trees. In addition, about 4 meters from the tree a remnant of a Bronze Age stone wall was observed, indicating that the tree grew near a settlement (Figure 2). If the tree had been killed, for instance by lightning, the inhabitants would most likely have used it for fuel, unless of course the dead tree had deliberately been left standing, perhaps for religious reasons. If so, the bark would probably have been weathered away in not too many years. The precursor layer is also observed in the Akrotiri excavation according to Domanov (1974), followed by the same characteristic pumice layer of the Minoan eruption.

*Figure 2: A. An olive tree growing close to a man-made Bronze Age wall. B. In the initial phase of the eruption the southwestern part of the ring faulted (Akrotiri Peninsula) was hit by a hot volcanic blast. As a result, the leaves of the trees dried up immediately. They fell down and were embedded in the white pumice dust covering the surface. This precursor layer is only 0.5 cm thick. C. In the first phase of the Minoan eruption, falling pieces of pumice almost covered the olive trees with a 4 cm thick pumice layer. The still warm pumice charred the trees.*

Has the irregularity of olive growth rings any effect on the calibrated date?

When “events” are dated using dendrochronology or radiocarbon dated charred trees the youngest tree-ring is a “terminus post quem” date for the event. To get a date close to the event the presence of the last-formed tree-ring, called “wane” edge or “terminal ring” is essential. Its presence implies that the sample is complete to the last year of growth. Even if the presence of the wane edge in subfossil wood is often missing there are ways to estimate the date of the tree’s death with some degree of certainty from remnants of sapwood rings, from wood anatomical aspects, or when the dimension of the tree can be estimated, i.e. from stake spur or, regarding the Santorini wood, from the dimension of the hole in the pumice.

Here we present arguments for the presence of the original outermost ring (wane edge) on the olive branch from Santorini:

1. On the olive section the outermost ring is identical on different radii and is unbroken all around the section, even if the section of the branch is not concentric. The non-concentric shape is typical for branch wood because of reaction wood, which stabilizes horizontal branches. If one postulates that due to degradation wood from the outside would have rotted away, it would be highly unlikely that the branch rotted exactly along the same tree ring, especially when the rings are not concentric.

2. We observed and documented the impression of bark in the pumice inside of the holes where we found the branch. Except for the weathered end of the branch and the mold close to cliff surface, the branch (and neighboring smaller ones) fit fairly tightly in the mold, indicating preservation of the branch surface at the section that we dated, with only a slight shrinkage due to charring. The amount of shrinkage of 7-13% longitudinally and 12-25% radially/taegetially is well established (Schweingruber 1990) and could be confirmed by our carbonization experiments on wood from living olive trees from Santorini.

On the other hand, the transition from the stem to a branch or from a first order branch to a second order branch the outermost ring follows the surface along to that branch. The outermost ring of the section of the first order branch is therefore identical to the outermost ring of the second order branch. This is what we observed on the olive branch from Santorini, where the outermost ring of a branch (second order) corresponded to the outermost ring of the first order branch. If we assume that external rings would have decayed, it is extremely unlikely that this degradation would happen exactly along the same tree ring for the two branching levels. The erosion of wood within the same tree ring over larger distances and along different structures (i.e. stem, branches) can be observed only among natural boundaries like the “wane edge,” or at strong density boundaries, i.e. the distinct heartwood-sapwood boundary in most oak species, which is in the same ring all along the section (Friedrich and Hennig 1996). In contrast, it took-ground, the sapwood boundary in olive wood is irregular. In addition carbonization enhances the resistance to biological degradation and minimizes the differences of wood resistance between hardwood and sapwood. It is therefore very unlikely that the observed uninterupted outermost tree ring on the olive branch section is a result of a degradation of external wood, but on the contrary we are confident that it really represents the wane edge (terminal growth ring). Even with the outermost ring preserved, a source of error in the wiggle-match calibration could arise from a too high ring count due to false identification of growth rings or a low count due to missing or unidentified rings. A review of Mediterranean tree growth patterns by Cherubini et al. (2003) has shown that the Mediterranean tree (Erdal et al. 2003) (granberry tree) is particularly sensitive to climate changes. It exhibits occasional intra-annual “false” rings, which may in some cases be difficult to identify and could therefore lead to falsely high ring counts, although by no means with two annual rings as a typical figure, let alone three. The same behavior could be suspected for olive trees growing in Santorini, but preliminary studies by one of us (M.F.) on recent olive wood from Sicily has not shown this effect. Ring counts on a polished section were in good agreement with results based on X-ray tomography and with the known age of the specimen. The known problems of indistinct growth ring boundaries in olive wood were overcome using the high resolution 3D-X-ray tomography technique. This technique helps to identify marginal
paraphrasmatic bands, which forms the ring boundary, much better than the traditional optical microscopic analysis.

We are aware that there still may be some missing or false rings in the olive branch section of Santorini, but we are confident that our error estimate of 25% encompasses every conceivable error margin (Friedrich et al. 2006: suppl. material).

Finally, if allowance is made for an exaggerated ring count in the wiggle-match dated Santorini olive branch, the calibrated date would tend to be even earlier than 1627-1600 BC. If, on the other hand, we assume that the ring count has been underestimated by ±25%, the calibrated date of the eruption would be only slightly later, i.e. 1635-1591 BC (5 sigma or 95.4% probability) (Friedrich et al. 2006: suppl. material). This is still far from reconcilable with a traditional archaeological date of 1550 BC or later.

Was the tree contaminated by old CO₂?

Since the olive tree grew on a volcanic island, it is also relevant to consider the question of whether the radiocarbon dates might have been influenced by old volcanic CO₂. The Akrotiri excavation, where part of the dated material described by Friedrich et al. (1990) and Manning et al. (2006) was found, shows direct evidence of a long period of volcanic inactivity. Here the Minoan pumice was deposited directly on top of the Cape Riva ignimbrite, which has been dated to 19,000 BC. The distance between the Akrotiri excavation and the crater of the Minoan eruption is about 7km, far away from earlier present or present emmission points of volcanic gases derived from the active volcanic zone (Figure 4). Studies in Germany (Laicher See) and on Santorini (Palaikastro) by Bruns et al. (1980) and on the Azores by Pascue-Cascardi (1999) have shown that plants growing close to an emana- tion point of old CO₂ give falsely old radiocarbon ages. However, their studies also show that the effect is locally restricted to the order of 100 meters or less around strong sources of volcanic CO₂ in agreement with theoretical calculations of atmospheric mixing, and even within a caldera, contributions from volcanic CO₂ were below detection limits for plants growing outside this range (Pascue-Cascardi 1999). Likewise, Shore et al. (1995) tested plants from a site 10km from the rim of the Kilauea volcano complex in Iceland and saw no detectable effects. Taking into account that (a) the distance between the growth-site of the olive tree and the nearest point on the active volcanic zone is about 3.5km, (b) the distance to the eruption is about 5km, and (c) the tree was found on top of the pre-eruption caldera rim with good air circulation, ensuring both horizontal and vertical atmospheric mixing, it is unlikely that contamination with old CO₂ could have affected the olive tree. Last, but not least, neither faults nor old fumarolic fields or sites with iron oxide deposits were observed in the neighborhood of the tree. Thus, the tree rings must be considered to represent a reliable archive of atmospheric CO₂ in its seven decades of lifetime prior to the eruption.

Also, we exclude a significant local offset of the ¹⁴C ages of the tree-ring samples by volcanic CO₂ because in that case it would most likely be impossible to match the measured ¹³C sequence anywhere to the shape of the calibration curve. We observe a downward slope in our dating sequence (Friedrich et al. 2006), whereas one would expect an upward slope if the eruption took place around 1500 BC and had been contaminated with volcanic CO₂. The aging effect should, if anything, increase due to increased emission in the period up to the eruption.

A final consideration could be possible influence of old CO₂ from groundwater taken up through the roots. However, Tauber (1983) has shown by ¹³C measurements that even in extreme calcareous soil conditions the uptake of CO₂ from soil carbonate is indiscernible (0.12 ± 0.3%). From tree-physiology it is extremely unlikely that there could be any quantitative effect by CO₂ uptake through the roots. The uptake could only occur as CO₂ in water which is transported via xylem (pipes) through the stem to the leaves where wood-cellulose is produced. Because of out-gassing of CO₂ in the xylem on the transport through stem and branches the contribution of CO₂ from root uptake compared to the CO₂ derived from the air through the stomata in the leaves is negligible. (This argument may not apply to herbals, not-woody plants.)

Would the final result be different if older versions of the calibration curve were used?

The recommended ¹⁴C calibration curve, IntCal04 shows less high-frequency variation than the previous one, IntCal98, due to different procedures in averaging the contributions to each decadal bin in the ¹⁴C data set. Hence, the wiggle-match of the four ¹³C dates of the olive sections as shown in Friedrich et al., 2006, could be sensitive to the choice of the calibration curve. However, as documented in the supplementary material of Friedrich et al., 2006, after calibration using IntCal08 the high limit of the calibrated age range is within a few years of the result based on Intcal04, and the low limit may extend down to 1675 cal BC.

Is the OxCal program reliable?

It has been argued that the result of the wiggle-match of the ¹⁴C dates of the four olive sections may depend on the calibration program in a subjective way, possi-

bly suppressing ranges of the probability distribution. For our specific use of the modeling capabilities of OxCal it is important to note that the sequencing model employed here does not introduce any filtering; it only requires the sections to maintain the sequential order within the tree segment as an additional constraint during the calibration. It should also be noted that the calibration programs commonly in use now were rigorously tested for the statistical algorithms that are used to transform the ¹⁴C age distribution into the calibrated scale.

Conclusion

In conclusion, we emphasize that the olive branch is not just another sample in line with a multitude of previous (mainly single-year) samples for which radiocarbon dates have been reported. This is unique because it contains ordered information from approximately 72 tree rings with a well established association with the eruption event, unlike more circumstantial evidence such as long-distance correlation with ice cores or climatically affected tree rings.

In particular, we conclude that:

- The tree was alive and standing when it was buried on Santorini by the ashes of the Minoan eruption.
- It is unlikely that old CO₂ could have influenced the result of the radiocarbon dating.
- The tree is preserved due to light charring due to its proximity to the eruption point, while trees in the more distant Akrotiri site have decayed. Roots and leaves have not been sufficiently preserved to allow radiocarbon dating.
- All the tree rings of the analyzed section of the branch were preserved, including the original outermost ring (water line). The well known irregularity of olive ring growth probably has a limited effect on ring counting, and even allowance for substantial errors in ring count would not rec-
Dating the Sant Radiocarbon: F (AD 2006–2007)

Stuart W. Ma, Thomas Hergarten, and Eva M. Wild

Abstract: "...There is a lot at stake in the [Santorini/Thera dates] debate. Until it is resolved, Warren says, at least for the Late Bronze Age, "we would have to forget about serious study of the past and relationships between peoples." (Balter 2006: 509).

Introduction

The recent publications and findings of Manning et al. (2006) and Friedrich et al. (2006), and previously those of Manning et al. (2002a), Manning and Brone Ramsey (2003) and Bronk Ramsey et al. (2004), on the dates of the Santorini/Thera eruption and the Late Bronze Age 1-2 cultural periods in the Aegean, have led to a variety of discussions both in print and informally. Whereas some archaeologists appear willing to engage or consider the new evidence and chronology, others reject this outright and regard radiocarbon as clearly wrong (see e.g. the selection of opinions reported in Balter 2006). Several scholars in the latter camp have in turn sought to suggest reasons why there perhaps is (or must be) something at error with the radiocarbon (14C) data employed in these studies, or the analyses, which might then somehow undermine the (otherwise) clear support these studies and their data currently provide for a "high" Aegean Late Bronze Age chronology. This discussion continues a new long-running thread in the literature from the mid AD 1970s to present, where radiocarbon data have (fairly consistently, but in recent work, with much greater precision) indicated an earlier date for the eruption and the beginning of the Late Bronze Age than previously thought (and still currently argued) from a conventional or "low" interpretation of the cultural linkages between the Aegean-East Mediterranean-Egyptian cultures (for a few examples, see: Michael 1976; Betancourt and Weinstein 1976; Betancourt 1987; Atken 1988; Manning 1988; Hardy and Renfrew 1990; Markelou et al. 2001).

At the Cornell Conference: Malcolm Wiener in a typically excellent and wide-ranging lecture raised a number of these concerns from a conventional chronology perspective (and see his paper in this volume for references to his other 2003 and 2006 to present publications, several of which raise some similar issues). It is thus appropriate to discuss such concerns and to offer some cogent on the soundness and clarity of the radiocarbon evidence (see also specifically the a number of these concerns from a conventional chronology perspective (and see his paper in this volume for references to his other 2003 and 2006 to present publications, several of which raise some similar issues). It is thus appropriate to discuss such concerns and to offer some cogent on the soundness and clarity of the radiocarbon evidence (see also specifically the

We offer this paper in honour of Peter Ian Kinzioulis and his three decades of work creating and leading the Aegean Dendrochronology Project and the Malcolm and Carolyn Wiener Laboratory for Aegean and Near Eastern Dendrochronology at Cornell University. The topic is appropriate as Manning first met Peter and Elvira on Santorini/Thera in 1989, where the Thera date was already (and also) topical and the scholarly field was seriously beginning to debate change. Today one is perhaps challenged by the well-known Buddhahsaying: “Everything changes, nothing remains without change.”

References


Supported by Online Materials published with the Manning et al. 2006a paper; Manning and Bronk Ramsey 2003: 124-129; Manning 2007; 2005; and the Friedrich et al. paper in this volume.

The main focus here is the c. 100-year conflict between the late to late 17th century BC calendar age ranges calculated for the date of the Akrotiri volcanic destruction level on Santorini/Thera (Manning et al. 2006a), or for the outermost ring of an olive tree killed by the eruption (Friedrich et al. 2006), versus the conventional chronology based dates for the eruption of c. 1525 BC or 1520 BC or 1500 BC (e.g. Warren 1984;