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ABSOLUTE CHRONOLOGY OF THE END OF THE AEGEAN BRONZE AGE

INTRODUCTION

In recent years the debate about the overall absolute chronology of the later phases of the Aegean Late Bronze and Early Iron Ages has been fuelled by radiocarbon and dendro-dates from two tell sites in central Macedonia, Kastanás and Ássiros. These dates have been taken to prove, or disprove, the traditional archaeological-historical chronology established since many decades (e.g. DESBOROUGH 1952, 294–295; cf. below). In the present paper we re-assess in detail the vertical stratigraphic sequences of both sites, and make proposals for the solution of the chronological problems posed by the radiocarbon and dendro-dates. We arrive at a new absolute phasing of the Late Helladic III C – Protogeometric periods.[1]

One of the long-standing problems in Aegean Bronze Age chronology is the existence of age differences (in the following: 'discrepancies') between the stratified calibrated radiocarbon dates from the site of Kastanás (WILLKOMM 1989), and the historical-archaeological dating at this site (JUNG 2002, 218–229. – IDEM 2003). The entire set of Early Iron Age ^{14}C-ages (from Level 9 onwards) appears systematically too old by several hundreds of years, independent of the dated material (tree charcoal, animal bones; see JUNG – WENINGER 2004, 217; 224–225). Even today, we have no explanation for these ^{14}C-ages. However, in previous studies (JUNG – WENINGER 2002. – IDEM – IDEM 2004), we have been able to explain at least some of the aberrant dates from Levels 16–10 in terms of an 'old-wood' effect, that is due to the dating of long-lived samples (wood, charcoal). We now take a closer look at the stratigraphic setting, functional use, and architectural positioning of these wood charcoals. It turns out that the dating bias caused by the 'old-wood' effect has some entirely systematic (and indeed 'cyclic') properties, which are best understood in terms of the site-specific burning events and subsequent rebuilding. However, in order to finally resolve the remaining ^{14}C-discrepancies for Levels 16–10, even this explanation is not sufficient. We conclude that, as part of the problem, in deriving absolute ages from the Kastanás ^{14}C-database we cannot simply use the recommended tree-ring calibration curve INTCAL04 (REIMER *ET AL.* 2004). Due to statistical over-smoothing, for certain time-windows in the Late Bronze Age, notably for single ^{14}C-ages but also under certain conditions for seriated ^{14}C-data, this calibration can produce major systematic offsets (> 100 yrs). The circumstances under which this occurs will be studied in detail, below. To avoid these offsets, we use the tree-ring calibration raw data as published by the laboratories Belfast and Seattle.

Kastanás is not the only site where major divergences between tree-ring calibrated ^{14}C-ages and historical ages are observed. Similar age differences, in the range of 50–150 yrs, are known from other sites in the Eastern Mediterranean (e.g. MANNING 1999. – VAN DER PLICHT – BRUINS 2001). Over the last decades major efforts to resolve these differences have been undertaken (e.g. BRUINS 1989. – BIETAK 2003. – BIETAK – HÖFLMAYER 2007), but remaining

[1] We thank Stefanos Gimatzidis for illuminating discussions on Macedonian Early Iron Age pottery.

dating discrepancies are sometimes generalized and taken as demonstration for the existence of two major disparate chronological systems, which itself causes further problems. Once such systems have been created, whether rightly or not, the discussion is further complicated, since mixing between such systems may lead to erroneous correlations (BRUINS *ET AL.* 2008).

The approach taken in the following paper is to step aside from generalizations, and return to the underlying archaeological and ^{14}C-radiometric data. We begin with a site-to-site approach, in which the dates from Kastanás and Ássiros are re-evaluated, followed by a region-to-region study, which includes a comparison of Greek, Italian and Swiss stratified finds (cf. JUNG 2006). Previous discussions of the Aegean Late Bronze Age ^{14}C-data have already focussed on such necessarily wide interregional synchronisms, but these studies are ultimately all referenced to the Egyptian pharaonic chronology (e.g. MANNING 1999). The Italian-Aegean studies, as presented here, give the discussion a new geographic perspective. The Italian sites can themselves be synchronized, across the Alps, with the Urnfield phases in Switzerland, for which important dendro-dates are available. The present paper is one component of a geographically wider research program, aimed at establishing a precise absolute chronology for the Aegean Bronze Age. However, to begin we must address the long-standing dating discrepancies as observed at the sites of Kastanás and Ássiros, which therefore occupy most of our present attention.

Recently for the first time a dendro-date was introduced into the debate, by Kenneth Wardle, Maryanne Newton and Peter Kuniholm (NEWTON – WARDLE – KUNIHOLM 2005. – WARDLE – NEWTON – KUNIHOLM 2007), and used to challenge the traditional absolute chronology of the end of the Aegean Late Bronze and beginning of the Early Iron Age. The newly dated wood samples are from the stratigraphy of Ássiros Toúmba, in the Langadhás Basin north of Salonica. The proposal of the scholars working with the Ássiros material is to date the beginning of the PG period to 1120 BCE,[2] rather than to the years around 1050,[3] 1025,[4] or even 1020/1000,[5] as in different conventional chronologies. This proposal is based on a network of dendrochronological synchronisms, as well as on the direct dendrochronological ^{14}C wiggle-matching for construction timbers from the mud-brick houses at the tell settlement of Ássiros. The new dendro-dates from Ássiros, which we consider correct (see below), have been combined with the Aegean relative chronology based on wheel-made painted pottery, but in a manner we do not consider correct (see below).

Of course, when selected for dating purposes, whether by dendrochronology or by radiocarbon dating, such long-lived (multi-annual) timber samples require careful scrutiny in terms of potential 'old wood' effects e.g. dating of inner growth-rings or secondary domestic or architectural use. Such caution is necessary, due to the high economic value of all forestry products, and most notably for the large wooden beams required for building purposes, especially when these have been adapted to major supporting functions (e.g. roof supports, doors, wall constructions). In the present paper, having first checked and confirmed the ^{14}C-based dendro-dating at Ássiros, we demonstrate that the dating is indeed likely to be affected by a secondary 'old wood' effect. In this specific case, we propose, the timbers were recycled, following deconstruction of the Phase 4 buildings, reuse in Phase 3, and subsequent recycling in Phase 2 due to their incomplete combustion during the destruction of Phase 3. This multiple recycling is entirely plausible, as will be argued, since the construction beams will have had sufficient mechanical stability, even after partial charring, for reuse in the next settlement phase. That such interpretational problems for the dating of charred wood samples were likely to occur at

[2] NEWTON – WARDLE – KUNIHOLM 2005, 185. – WARDLE – NEWTON – KUNIHOLM 2007, 495; 497 fig. 7.
[3] DESBOROUGH 1964, 241. – IDEM 1972, 79; 134–135.
[4] DESBOROUGH 1952, 294–295.
[5] MOUNTJOY 1988, 27. – HANKEY 1988. – LEMOS 2002, 26.

Kastanás, was already anticipated by the excavator, Bernhard Hänsel (HÄNSEL 1989), immediately after publication of the radiocarbon measurements by WILLKOMM (1989). According to HÄNSEL (1989, 8) such repeated reuse ("wiederholte Sekundärverwendung") of old timbers would have been a natural option for the inhabitants of Kastanás, due to the expected lack of good forests in this region. HÄNSEL (1989, 8) further mentions his hope that future ^{14}C-ages may be measured on short-lived grain samples. Unfortunately, such samples never became available in sufficient amounts for conventional ß-decay dating, nor did larger charred wood samples ever turn up, with sufficient ring growth for dendro-supported wiggle matching as at Ássiros.

Similar problems apply to the large majority of archaeological sites, anywhere in the world. At Kastanás, such critical properties of ^{14}C-ages undertaken on wood and charcoal samples have long been recognised as a cause for major discrepancies. At Kastanás, however, there appear to exist other problems of the ^{14}C-ages, that are not simply connected with sample taphonomy. These remaining discrepancies turn up just as much for ^{14}C-measurements on animal bones with clear terrestrial nutrition, as well as for animals with hypothetical mixed terrestrial and marine nutrition (possibly recognisable due to marine-near δ^{13}C-values).[6] As will be shown, there are strong indications that the remaining ^{14}C-discrepancies are caused by technical effects (over-smoothing) related to the construction of the tree-ring calibration curve, during the second millenium calBC. If confirmed, this proposal may have consequences beyond the present study. We underline our results, therefore, by demonstrating that similar effects apply to calibrated ^{14}C-ages for other periods. This is shown in a complementary case study towards the chronology of the Early Neolithic Linearbandkeramik culture (LBK), that is for ages c. 5500–4900 calBC (cf. below). In both case studies (Kastanás and LBK) some relatively large proportion of the archaeological ^{14}C-ages were measured at the Köln laboratory (Lab code: KN). For systematic reasons, therefore, we begin our studies by analyzing the precision and accuracy of the KN-measurements. It must be emphasised, however, that our argumentation is independent of any specific archaeological data.

KÖLN RADIOCARBON LABORATORY. INTERCOMPARISON RESULTS

The radiocarbon laboratory at the Köln University (Lab.Code: KN) is actively involved in the inter-calibration and quality control studies of the International Radiocarbon Community (e.g. SCOTT, 2003. – SCOTT 2007). These interlaboratory studies are aimed at supplying individual laboratories with external expertise concerning precision and accuracy of ^{14}C-measurements, as obtained by a large number of participating laboratories. Tabs. 1 and 2 show the ^{14}C-ages achieved by the Köln laboratory for a set of nine intercomparison samples (wood, cellulose, turbidite, barley) in comparison to the results obtained by statistical analysis of a large number (N~92) of independently participating radiocarbon laboratories using different measuring techniques (^{14}C-AMS, liquid scintillation, ß-decay counting). With given highly satisfactory agreement, it suffices to state that the archaeological ^{14}C-radiometric discrepancies under study in the present paper are unlikely to have been caused by imprecise KN-measurements.

GAUSSIAN MONTE CARLO WIGGLE MATCHING

Our studies require a second brief introductory section, in order to describe the methodology of Gaussian Monte Carlo Wiggle Matching (GMCWM). The basic methodology underlying GMCWM is outlined by WENINGER 1997. Since then the method has been refined, to allow for

[6] But see JUNG – WENINGER 2004, 224 for the difficulties in identifying the effects of feeding from a mixed carbon reservoir.

a wider field of applications. The GMCWM approach is an extension of the Wiggle Matching method developed long ago (PEARSON 1986. – WENINGER 1986), and now widely used in the analysis of sequenced ^{14}C-data (e.g. tree-ring sequences, archaeological data sets). A comparison of Wiggle Matching methods is given by BRONK RAMSEY *ET AL.* 2001. The idea underlying the GMCWM extension is that it may be useful to estimate, under as realistic as possible conditions, the overall dating error for any given archaeological age-model based on seriated ^{14}C-ages. In its present technical realisation, the method is limited to the analysis of linear age-models. However, assuming this limitation can be accepted (as is the case for tree-ring sequences), the method may be used to some advantage, due to its flexibility in error definitions, to derive numerically highly precise wiggle matching error estimates. Basically, just as in the classical linear wiggle matching approaches, in GMCWM the user is first obliged to formulate a distinct (quantitative) age-model for the ^{14}C-data under study. This kind of age model has the appearance, simply, of a list of ^{14}C-dated samples arranged according to the independently established stratigraphic order. Starting by convention with the youngest ^{14}C-dated sample as reference (distance = 0), for each ^{14}C-age/sample a numeric estimate of the calendric age distance to the next older sample is defined. An example of such a sequence, that is ready to be entered into the GMCWM algorithm, is given in Tabs. 4a, 4b.

In a computationally intensive process, the GMCWM-procedure then repeatedly fits the calendrically seriated ^{14}C-age/sample pairs to the calibration curve. The number of runs is chosen (Nmax=10.000) according to the numeric precision required for the overall dating error. During each run the best-fit year, on the calendric-scale, is calculated. This year is stored, along with its probability, and the run is repeated. Prior to each new run, the input data is varied, according to three independently running random number generators. These generators are used to define Gaussian distributions corresponding to (i) simulated repeat measurements of the entered archaeological ^{14}C-ages, (ii) simulated repeat measurements of the entire calibration curve, and (iii) simulated repeat measurements of the listed calendric-scale distances. As a result of the applied generic procedure, finally, a distribution of best-fit yrs on the calendric timescale is obtained. Experiments show that similar results are achieved, when equal weights are applied to each best fit-yr, or when the calculated (variable) dating probability is applied as statistical weight to each run. To conclude, by simulating (Gaussian) dating errors for the archaeological age-model on both time-scales (^{14}C and calendric), as well as by simulated repeat construction of a new calibration curve for each run, the method of Gaussian Monte Carlo Wiggle Matching can be used to derive a precise estimate of the overall dating error for the age model under study. The GMCWM method is integrated in the CalPal software package (www.calpal.de). The method is programmed to supply a numeric precision of 1 year on both timescales (^{14}C and calendric).

KASTANÁS RADIOCARBON CHRONOLOGY

The database (Tabs. 4a, 4b)[7] contains a total of N=60 ^{14}C-ages (overall Kastanás Levels 16 to 6), of which 45 ages were measured on charcoal and 15 ages were measured on animal bone. As discussed in JUNG 2002, using synchronisms of critically selected pottery finds from Kastanás with stratified parallels from sites in southern and central Greece (such as Mycenae, Tiryns, Lefkandí and Peratí), which are in turn linked to the historical chronology of Egypt (by contexts in the Levant and Egypt), for many of the architectural phases at Kastanás it was possible to derive a unique archaeological-historical age with expected dating precision in the range of a few decades. Based on further stratigraphic and taphonomic analysis of individual ^{14}C-samples, including linear age interpolations on the architectural intraphase (~10–30 yrs)

[7] New dates are described in Tab. 3.

level, this chronological system was then used to derive an archaeological-historical age for each ^{14}C-dated sample. We have arranged these archaeological ages in Tabs. 4a, 4b, along with the corresponding (conventional) ^{14}C-ages, measured stable carbon fractionation (δ^{13}C, permille PDB), reference to the dated material (e.g. charcoal, bone), as well as designation of the architectural phase from which the dated material derives. The expected calendric ages are nominated as "hist. BC" (column 7). In this table, we purposely refrain from giving tree-ring calibrated ages for individual ^{14}C-ages.[8] It is further emphasised that, for the purposes of the present paper, we only pay attention to the ^{14}C-ages from Levels 16–10. The reason is that the stratigraphically younger samples (both charcoal and bone) from Kastanás Levels 9–6 (~ 900–700 hist.BC) have ^{14}C-ages that still today allude all explanations. For completeness these ^{14}C-ages are included in Tab. 4a (nos. 1–13), but are excluded from the present analysis. The set of samples (Tabs. 4a, 4b, nos. 14–60) under study in the present paper, have an oldest expected age of 1365 hist.BC (Tab. 4b, no. 60) and a youngest expected age of 910 hist.BC (Tab. 4a, no. 14).

KASTANÁS RADIOCARBON CHRONOLOGY
ALTERNATIVE AGE MODELS AND DISCREPANCIES

As already stated in the introduction, at Kastanás there is the long-recognised problem that the available large set of ^{14}C-ages (Tabs. 4a, 4b) shows systematic deviations from ages derived by historical reasoning. These deviations amount to an average of ~140 yrs on the calendric age-scale (cf. JUNG – WENINGER 2004, 216), with the ^{14}C-ages ranging systematically older than the historical ages. These clearly non-trivial deviations are illustrated in Figs. 1 and 2. Both graphs show exactly the same stratigraphically sequenced set of ^{14}C-data (we call *data package*), and both graphs use exactly the same quantitative estimates for the (calendric) time duration of Kastanás phases. Depending on the construction method, there are major differences in these graphs. Fig. 1 shows the *statistical age-model,* achieved by fitting the data package to the calibration curve by statistical procedures.

Fig. 2 shows the *historical age-model*, achieved by setting the same data package to the calendric time-scale according to historical expectations. To begin, we acknowledge there are seemingly good reasons to give preference to the *statistical age model* (Fig. 1). In this model, the ^{14}C-data bars show a comparatively small spread around the calibration curve. The spread is furthermore symmetric i.e. the data *above* the calibration curve are clearly balanced by the data *below* the curve. This is, of course, a direct consequence of the applied statistical method, which has been engineered to do exactly that: precisely and accurately balance the data around the calibration curve, according to the statistical weights of given measurements. This balancing is organised to be effective, by statistical criteria, over the entire length of the calendric window covered by the archaeological sequence. We will return to this important point, below.

In contrast, the same sequence of ^{14}C-ages, when set according to the *historical age model,* shows a clearly visible systematic offset of some 100–150 ^{14}C-yrs against the tree-ring calibration curve. There is some variability in the spread of data, depending on Kastanás phase, but the data invariably show older ^{14}C-ages than expected for contemporaneous dendro-dated tree-rings. This offset shows up for the majority of ^{14}C-ages from all architectural Levels (16–10).

[8] Due to strong atmospheric ^{14}C-variations and associated non-linear shape of the age-calibration curve, such calculations performed for isolated single ^{14}C-ages produce little more than misleading lists of alternative calendric age intervals. It is also to be questioned whether the supposedly variable dating probability, assigned to such intervals by standard ^{14}C-calibration software packages (e.g. OxCal, Calib, Cal25), is really significant. If calibrated ages for single ^{14}C-dates are really deemed necessary, our proposal is to calculate the 95 %-confidence limits for the calendric scale probability distribution, and use the half-length of this interval ("FWHM=Full Width Half Maximum") to measure the cal-scale 68 %-confidence interval. Such methods are widely applied in nuclear physics for peak-shape analysis e.g. in high-resolution γ-spectroscopy (cf. WENINGER 1993).

Due to the clearly systematic appearance of this offset, there are seemingly good reasons (as proposed e.g. by TRACHSEL 2004, 166–168 and NEWTON – WARDLE – KUNIHOLM 2005, 186) to enrole the existence of a major error in the historical dating at Kastanás. Before perpetuating such wrong conclusions (TRACHSEL 2004, 166–168), however, let us take a closer look at the data. In our opinion, in spreading systematically above the calibration curve in this manner, the majority of ^{14}C-ages from Kastanás are doing exactly what we would expect for 'old wood' samples. That is not the problem. However, what we do consider curious is the clearly visible jump of the data from Level 13 (with three values *below* the calibration curve) up to Level 12 (with a cluster of ^{14}C-values all *above* the calibration curve, around 1120 calBC). We adress this conspicuous jump of the data below.

Before continuing, we conclude, the *statistical age model* (Fig. 1) has some clear merits due to the apparent symmetry of the dating solution. We nevertheless prefer the *historical age model* (Fig. 2), mainly because the systematic setting of the data *above* the calibration curve (towards older readings) corresponds to what we would expect for a major selection of 'old wood' samples. The remaining problem, *for the historical age model*, is the rather extreme 'old wood' age of many of the dated samples. A neutral comparison of both age-models shows that the statistical solution places the architectural phases 16–10 at an average ~140 yrs older than expected on archaeological grounds. These dating solutions, and the age differences obtained, are relatively stable against variations in the average phase length.

THE STRATIGRAPHY OF KASTANÁS

It is necessary to elaborate further on the stratigraphic sequence of the tell site at Kastanás. Above, we have focussed on analysing the large number of ^{14}C-dates on charcoal and animal bones now available as a background to dating the uninterrupted vertical sequence of Levels 16 to 10. Those settlement Levels are all well dated by wheel-made pottery to the time span from LH III A Late to LPG. In their discussion of the published dates from Kastanás, first Martin Trachsel (TRACHSEL 2004, 166–168) and later Wardle, Newton and Kuniholm (NEWTON – WARDLE – KUNIHOLM 2005, 185–187) did not adequately take into consideration the stratigraphic evidence underlying these dates, although this was described in much detail, in two earlier papers (JUNG – WENINGER 2002. – IDEM – IDEM 2004).[9]

In the present paper we take a fresh view of the stratigraphy and its chronology, which we can now base on a new set of radiocarbon dates, measured to the highest possible analytical precision as achievable at the Köln radiocarbon laboratory. Although this admittedly necessitated lumping of different animal bones, for four of the total six new dates, in order to obtain the large amount of carbon required for the applied method of conventional ^{14}C-beta-decay measurements, we are confident that the stratigraphic location of these samples is correct, as given in Tab. 3.

We have already made reference above to the archaeological age-model developed for Kastanás (Tabs. 4a, 4b). This is a combination of stratigraphic positioning of each sample inside its architectural Level, the stratigraphical evidence for the relative duration of each building Level, and the historical-archaeological dating of these Levels. Subsequent to its construction, this age-model was independently tested by comparison of the ^{14}C-sequence with the high-precision radiocarbon calibration curve INTCAL04 (Fig. 4). Altogether, we found the best agreement between the archaeological and radiocarbon age-models for an average shift of the dates obtained on charcoal in the sample sequence of 15 yrs older than the initial archaeolo-

[9] Apart from that, there are other problems with Trachsel's proposal. He does not take into consideration regional stylistic variations of Aegean-type pottery and their dating range, he does not discuss the stratigraphical contexts of the pottery, which are dated by historical sources, and does not use the correct phase terminology for the LBA Aegean (cf. TRACHSEL 2004, 196 fig. 109).

gical proposal. Such a shift can easily be explained as the minimum amount of carbon (at Köln: c. 3 grams) necessary to process a conventional radiocarbon date at high precision. This amount will automatically, indeed unavoidably, comprise material from quite a large number of tree rings (> 10–20). In consequence, the carbon sampling itself introduces a shift of the date backwards in time, away from the cutting event. The bone dates do not appear age-shifted in this manner, at least not on the scale (~15 yrs) of the wood charcoal dates, since most of the animals were regularly slaughtered well before reaching 10 years of age.[10]

We observe, further, that actually only very few dates from Levels 16, 15, 14b and 14a fit well with the archaeological-historical age expectations. This is because most of the charcoal samples from these Levels have a significant 'old wood' effect, in strong contrast to the short-lived bone dates from the middle and later part of Level 16, which can be attributed to the wiggle at 1330/1325 calBC. The overall picture, here, is that the charcoal and bone samples from the same architectural levels show large differences in age.

Interestingly, this picture changes in the later Levels. A striking example is provided by the dates for Level 13, nearly all of which immediately agree quasi-perfectly with the historical-archaeological chronology. In fact, this applies also to the two bone dates (KN-5238 and KN-5239). But they should also have been set around 1170 hist.BC, because stratigraphically they belong to the beginning or at least the first half of the use period of Level 13. For stratigraphical reasons they are, in fact, only shortly younger than the charcoal samples, which date from the construction period of the houses. Note here, we have spread the 5 dates of Level 13 slightly, to increase their graphic visibility. In fact, four (KI-1788, KN5239, KN-5238, KI-1789) out of five dates from Level 13 can be ascribed to the region of the downward wiggle around 1180 calBC (Fig. 6), the existence of which is confirmed by analysing the raw data from which the INTCAL04 calibration has been constructed (Fig. 3; zoom in Fig. 5).

A similar exact agreement with the historical age expectations is found in six dates on charcoal from Level 12, which come from very different parts of the settlement and can mainly be ascribed to construction timbers (cf. already JUNG – WENINGER 2002, 290. – IDEM – IDEM 2004, 217).[11] They centre around the upward wiggle around 1130 calBC (Figs. 4 and 6).

In Level 11 two dates on charcoal may show the expected 'old wood' effect, while a third one from the outer tree rings of a wall post in the Central House (KN-5024: 2839 ± 34 BP) is in very good agreement with the archaeological age-model (see also JUNG – WENINGER 2002, 289–290). The two bone dates (KN-5234 and KN-5235) give ^{14}C-ages older than expected by the archaeological age-model. Since both samples show enriched δ^{13}C values, hinting at some dietal effects, this appears to have influenced the ^{14}C ages obtained on the collagen (JUNG – WENINGER 2004, 223–224).[12] Similar enriched values are found in most of the bones of the younger Iron Age Levels 9–6, which show marked deviations from the archaeological age expectations[13] (Tabs. 4a, 4b).

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[10] For the species represented in the ^{14}C-bone samples see Tab. 3 and in addition JUNG – WENINGER 2004, 222 tab. 3. These are red deer, fallow deer, cattle, pig. – See BECKER 1986, 31 tab. 5; 32; 64–65 tab. 23; 119 tab. 48; 129 tab. 55.

[11] The dates KN-2584 and KI-1982 are not discussed here because of their high standard deviations.

[12] The pronounced divergence of the bone date KN-5235 from the archaeological-historical age expectation may theoretically be due to stratigraphical disturbance. The sample comes from an area in the Central House of Level 11, which is partially disturbed by a pit from Level 10 (cf. HÄNSEL 1989, plan 16, squares Z–AB 55–57). Apart from that, the stratigraphic separation of that building from its predecessor in Level 12 was difficult due to the partial disturbance of that area and to the end of the excavation, which prevented further investigations of the Level 12 building (cf. HÄNSEL 1989, 199–203). The other bone sample of Level 11 (KN-5234) also comes from the area of the former Central House, but not from any disturbed context.

[13] The dates of these Levels will be discussed in relation to the archaeological-historical age expectations, once the relative chronology of the later Iron Age Levels has been finally established by Stefanos Gimatzidis, who is studying the wheel-made pottery of Levels 9–1.

For Level 10 all three animal bones and one charcoal date with low standard deviation (KN-5063) confirm the archaeological chronology.

A good and we think at any rate immediately plausible explanation for the altogether quite complicated pattern of agreements and non-agreements between the ^{14}C data, and the historical-archaeological chronology, becomes apparent, when we look at the different house construction techniques in use from Levels 16 to 10. From Level 18 onwards houses on the toúmba of Kastanás were built basically with mud-bricks, in combination with some wooden posts set close to or directly into the walls (HÄNSEL 1989, 70–146 plans 8–13.) This changed with Level 13, a phase in which wooden houses prevailed and mud-brick walls were an exception (HÄNSEL 1989, 147–171 plan 14). People now had to cut fresh trees in large quantities. The availability of reusable wooden posts would have been minimal because of the small number of houses in use during the preceding Level (HÄNSEL 1989, 135–146 plan 13). Thus, we can expect that the charcoal dates for Level 13 are directly related to the construction of the houses. When Level 13 was destroyed by fire, nearly no construction elements of the light wooden buildings would have survived the catastrophe. Therefore, again, newly cut trees would have been necessary to erect the mud-brick houses of Level 12 (for these buildings see HÄNSEL 1989, 171–190 plan 15). This explains the very short time interval (between 2950 and 3000 BP) covered by the dates on charcoal from Level 12. The destruction of Level 12 was not a total one. The excavator Bernhard Hänsel stressed that in the following Level 11 one can observe the existence of partially preserved buildings, that were reconstructed and reused. A new overall town planning could not be observed (IBIDEM, 190–208; esp. 193 fig. 77 plan 16). The two 'old wood' dates of Level 11 can be explained in this way. Level 10 was again predominantly characterized by light wooden dwellings (IBIDEM, 208–222 plan 10). One of its charcoal dates (KI-1785) clearly shows an 'old wood' effect, probably resulting from a reused construction timber. Another date on charcoal (KN-5063) is a young-wood date that clusters along with the bone dates in the second half of the 10th century calBC. It may belong to repair work at the end of the phase.

This re-assessment of the Kastanás sequence now offers a clear explanation for the seemingly confusing mixture of 'old wood' effects and partial agreements of radiocarbon and historical-archaeological chronology. Interpreted in this way, the sequence of radiocarbon dates from Kastanás now supports some new and we think highly significant conclusions concerning the absolute chronology of the Aegean Late Bronze Age. The dates from Levels 13 and 12 are especially important in this context, first, because they fit neatly on the downward wiggle around 1180 and the upward wiggle around 1130 calBC and second because the relative phase duration of Level 13 restricts any major shifting of the dates for Level 12.[14]

In terms of relative chronology, the houses of Level 13 were built at the beginning of LH III C Developed or in a developed stage of LH III C Early, while those of Level 12 were erected during LH III C Advanced. This suggests a start of LH III C Early one or two decades before 1200 and a start of LH III C Advanced around 1150/40 BC. For the start of MPG a date on the splint of a post from Level 11 (KN-5024) gives a hint at the years around 1000 calBC. The cluster of Level 10 dates anchor LPG well into the 10th century calBC.

[14] Contrary to what NEWTON – WARDLE – KUNIHOLM 2005, 186 state: "In any case this mean determination for the set from Schicht 12 can equally well be placed on any of the three peaks in the calibration curve between 1200 and 1100 BC and there seems to be no good reason for preferring any of these matches above the others without independent evidence."

CALIBRATION CURVE CONSTRUCTION SAMPLE-WIDTH DEPENDENT ^{14}C-CALIBRATION

As already recognisable in Fig. 2, and showing up more clearly in context with the calibration raw data (Fig. 6), there is a conspicuous jump in ^{14}C-ages from Kastanás Level 13 to Level 12. This jump could simply be the chance product of biased archaeological sampling, or of natural fluctuations in the ^{14}C-measurements. However, beyond its being highly reproducible in the archaeological ^{14}C-sequence, there are further reasons to adress this jump in more detail. Clearly, if this jump in the archaeological data is real, and corresponds to a similar jump in the calibration curve, the historical dating of Kastanás Levels 14b–12 underlying the samples at stake would thereby achieve an independent (tree-ring based) confirmation, on a hitherto unachieved level of confidence. Before submitting to this conclusion, it appears wise to study the properties of the underlying ^{14}C-calibration data in more detail. The same need for cautious argumentation also applies to the Kastanás data in the region of c. 1330 calBC (Fig. 7, right), where there is a another conspicuous wiggle (or another group of misplaced calibration raw data: Fig. 7, left). Such data structures are difficult to analyse, since they have extremely low signal-noise ratios and may therefore be (suggestively) produced by artificial effects e.g. chance variations in measuring precision or data density.

Most larger archaeological data sets contain a sample admixture that includes both short-lived samples with annual growth period (e.g. grain), intermediate-life samples with carbon accumulation over some few years (e.g. animal bones), as well as long-lived samples with multi-decadel growth period (e.g. wood or wood-charcoal). Depending on the amount of time covered by the sample, in theory there exists – for each sample-type a different (sample-width specific) ^{14}C-age calibration curve (MOOK 1983). Due to limitations in technical resources, beginning with the earliest consensus calibration (KLEIN *ET AL.* 1982), in lack of annual measurements, the curves have always been built using decadel and bidecadel tree-ring blocks. Although not widely acknowledged in the user community, this general limitation of all recommended calibration curves has always been clearly stated in relevant publications (e.g. INTCAL86, INTCAL98), including the most recently ratified calibration INTCAL04 (REIMER *ET AL.* 2004). In search of a cause for the age-differences between ^{14}C-radiometric and historical chronologies for the Aegean Late Bronze Age it is, therefore, quite natural to include a detailed analysis of the technical specifications of INTCAL04 in these studies. There may be other properties of the calibration, we should also adress (e.g. regional offsets, carbon reservoirs, seasonal growth differences). However, for reasons that will soon become apparent, it is sufficient to address one main technical parameter of the calibration curve, that is its shape (smoothness) in relation to the underlying raw data.

CALIBRATION CURVE CONSTRUCTION (INTCAL98, INTCAL04)

The overall time-window under study in the present paper is 1600–800 calBC (3550–2759 calBP). However, since our focus is on understanding the archaeological ^{14}C-ages from Kastanás phases 14b–12, it suffices to zoom into this time-window at two different positions, (i) 1260–1100 calBC and (ii) 1420–1280 calBC. The rawdata underlying construction of the calibration INTCAL04 in these time-windows is assembled in Tab. 5 and Tab. 6, along with complementary high-precision measurements of the Heidelberg laboratory.

Participating laboratories are Belfast (Lab Code: UB) and Seattle (Lab Code: QL), with tree-ring measurements based on Irish Oak (UB) and southern German Oak (QL). Upper limit interlaboratory offsets between Belfast and Seattle, for these data sets, are estimated to be -6 ± 1 ^{14}C-BP, with Belfast producing the (insignificantly) younger values (REIMER *ET AL.* 2004, 1035: tab. 1). In the construction of INTCAL04, no corrections were undertaken to allow for these differences (REIMER *ET AL.* 2004, 1035). The data shown in Tab. 5 (1250–1100 calBC) and Tab. 6 (1450–1260 calBC) includes further high-precision ^{14}C-measurements performed at the Heidelberg laboratory (Lab Code: Hd), but which are not included in the calibration INTCAL04 since they were derived from a floating component of the Anatolian tree-ring chronology, as published by KROMER *ET AL.* 2001, with updates by MANNING *ET AL.* 2003. Estimates by REIMER *ET AL.* (2004, 1035) of the interlaboratory differences between Heidelberg and Seattle give values in the range of 15 ± 3 ^{14}C-BP, with Heidelberg giving slightly older values, although differences are again hardly discernable.

BAYESIAN PROCESS MODELLING

Whereas previous radiocarbon age-calibrations (INTCAL86, INTCAL93, INTCAL98) were based on relatively simple data averaging procedures (e.g. WARD – WILSON 1978), with the inception of INTCAL04 (REIMER *ET AL.* 2004), statistically more advanced methods of calibration curve construction based on Bayesian process modelling have been implemented (BUCK – BLACKWELL 2004). Perhaps most important is, as stated by BUCK – BLACKWELL 2004, that the new INTCAL04 calibration (i) accounts for calendric time scale uncertainties (which were previously ignored) and (ii), that the new Bayesian construction method allows for errors due to correlated measurements. This type of error (covariance) is typical e.g. for calendric age-models based on direct counting of consecutive events (i.e. tree-ring dates, wiggle matching, varve-counting), in which case errors may accumulate. Such errors will typically also occur in archaeological studies (e.g. during interregional transfer of pottery synchronisms), and quite generally in the synchronisation of age-models (e.g. correlation of climate proxies, ice-core synchronisation).

The implementation of this second error component, to allow for covariant errors, in the new INTCAL construction methods is clearly tailored not so much towards the Holocene tree-ring section of the calibration, but rather to its extension into the Glacial periods. In the Glacial periods beyond 26 ka ^{14}C-BP the INTCAL-community has identified (VAN DER PLICHT *ET AL.* 2000) a number of still now officially unresolved discrepancies (VAN DER PLICHT *ET AL.* 2004. – BRONK RAMSEY *ET AL.* 2006) between potential calibration datasets. These datasets can be derived from so many different sources (e.g. U/Th-ages on pristine corals, marine data, ice-core synchronisms, stalagmites), that the occurrence of such age differences is not unexpected. As proposed by JÖRIS – WENINGER 1998, one of the major causes of these differences is to be sought in the age-models underlying the Greenland ice-models (GISP2 & GRIP). For an up-to-date account of glacial ^{14}C-age calibration cf. WENINGER – JÖRIS 2008. As goes for the Holocene, under study here, it is indeed important that such correlated uncertainties are included in the ^{14}C-age calibration (BUCK – BLACKWELL 2004). Let us therefore have a closer look at the procedures by which this error analysis is established in the INTCAL04 calibration.

RANDOM WALK MODEL

As applies to the overall Holocene section, and hence also covering the time window (1600–800 calBC) under study in the present paper, all previous calibrations (INTCAL93, INTCAL93, INTCAL98) were constructed by calculating a weighted average of all ^{14}C-data within a 10-yr calendric window and assigning this value to the window mid-point (REIMER *ET AL.* 2004, 1036). Bidecadel tree-ring samples were treated as two independent decadel blocks. Subsampled decades were binned as if they were decadel (REIMER *ET AL.* 2004, 1036). This procedure was used, due to lack of ^{14}C-data for annual samples. Major exceptions are for the periods 1510–1954 calAD (STUIVER *ET AL.* 1998a), 3903–3192 calBC (N=90, Groningen), and 2294–1934 calBC (N=45, Pretoria). In consequence, most sections of the Holocene calibration are constructed from overlapping decadel and bidecadel ring blocks. Both effects, the finite block width as well as block overlapping, cause an in-built smoothing of the atmospheric

^{14}C-variations. As emphasised by the authors, it was an explicit goal of the new statistical modelling procedures implemented in INTCAL04-construction to allow for calendric interval overlapping, as well as for co-correlations of neighbouring values. This is formalized in an approach based on a Gaussian Random Walk (GRW) smoothing model, in which the changes in atmospheric ^{14}C from one year to the next are described using a Gaussian distribution with mean (or 'drift') ß and variance (per year) r^2. Actual values used in the construction of INTCAL04 are ß=1 and $r^2 = 64$ (i.e. r=8) (BUCK – BLACKWELL 2004, 1099). Use of the value ß=1 is due to the expected change of the calibration curve by approximately 1 ^{14}C-calibrated year for each consecutive solar year (BUCK – BLACKWELL 2004, 1099). The *a priori* less clear choice of the annual variance r^2 of this change was based on numeric simulations using the single-year data supplied by STUIVER *AT AL.* 1998b. These simulations, as well as later construction of the INTCAL04 curve, were based on data blocks with length 100 yrs (BUCK – BLACKWELL 2004, 1099. – REIMER *ET AL.* 2004, 1036).

SMOOTHING EFFECTS

For all practical purposes this means that, in the construction of INTCAL04, a smoothing algorithm has been applied to the calibrated rawdata. The procedure is based on a randomizing Gaussian distribution with width r=8 yrs on the calendric scale (BUCK – BLACKWELL 2004, 1099). The underlying statistical model corresponds to the geophysical assumption that there is equal probability for a rise or fall in atmospheric ^{14}C-levels, in consecutive years.

According to REIMER *ET AL.* (2004, 1036), the validity of the RWM has been tested by comparing the distribution of shifts in consecutive decadel bins, of derived ^{14}C-values to be used in calibration curve construction, as obtained by the two methods (i) the 'classical' binning method (used in INTCAL98), and (ii) the RWM (as used in INTCAL04). According to REIMER *ET AL.* (2004, 1037 fig. 2) the two methods give very similar distributions. REIMER *ET AL.* (2004, 1037) conclude that, due to this successful testing of the RWM approach, the underlying basic assumptions of symmetric atmospheric ^{14}C-production and oceanic ^{14}C-absorption are indeed supported by the data, on average for the entire Holocene. The question remains, of course, whether this generally valid assumption also holds for each individual 100-yr subinterval of the calendric time scale, and notably whether it holds for the strong wiggles (e.g. at ~1180 and ~1330 calBC) identified as important in understanding the Kastanás age-discrepancies.

To this question, the authors of INTCAL04 are careful in pointing out that INTCAL04 is "somewhat smoother" than INTCAL98 (REIMER *ET AL.* 2004, 1037). They emphasise further that wiggle matching of tree-ring sequences are "sometimes pushed to the limits" (IBIDEM), such that, when wiggle matching methods are applied, the new INTCAL04 calibration "may require some adjustment in methods".[15] These words of caution apply, in particular, to shorter series (REIMER *ET AL.* 2004, 1037).

[15] Our conclusion – that the INTCAL04 calibration is too smooth for many archaeological applications, and especially for short-lived samples – is independently confirmed by BRUINS *ET AL.* 2005. In their study of an Iron Age ^{14}C-series from Rehov (Israel) they state: "Most Groningen radiocarbon dates from Tel Rehov are based on seeds. Therefore, a calibration curve based on single year dendrochronological measurements would have been preferable, as stated by Mook and Waterbolk (1985: 22): 'the ^{14}C sample and the calibration data should have the same time-width (growth-period)'. Such a curve is not available for the approximate time-period 1200–600 BCE of the Levantine Iron Age. Since the 1998 calibration curve (Stuiver et al. 1998; Stuiver and van der Plicht [eds.] 1998) is more detailed than the smoothed 2004 version (Reimer et al. 2004), the former has been used rather than the latter. The more detailed IntCal98 calibration curve was used, though some comparisons were made with the smoothed IntCal04 curve." In our opinion, however, the INTCAL98 curve is itself in many places too smooth for calibration of short-lived samples. This is shown in our LBK example.

CALIBRATION CURVE CONSTRUCTION CASE STUDY FOR RADIOCARBON ANALYSIS: LBK CHRONOLOGY

According to the results achieved at Kastanás and Ássiros, there are two main effects leading to systematic deviations between ^{14}C-ages and archaeological dating, that is (i) potential misreadings due to selection of 'old wood' charcoal samples, and (ii) potential misreadings due to construction procedures of recommended tree-ring based calibration curves. Since neither of these effects has a site-specific component, they can both be expected to apply, quite generally, to all kinds of archaeological ^{14}C-data in the Holocene. These effects therefore require further attention. In the following chapter we adress the effects of calibration 'smoothing' in further detail, based on a case study towards the ^{14}C-chronology of the central European Linearbandkeramik culture. We also give procedures to identify corresponding age-deviations.

Both, independently, and in combination, the 'old wood' and 'calcurve smoothing' effects produce some rather strong distortions (range ~100 yrs) of archaeological radiocarbon chronologies. Perhaps contrary to what might be expected, curve-shape related distortions of ^{14}C-ages are quite commonplace in archaeology. Even if typically more attention is given to the 'old wood' effect, the curve-shape distortion of archaeological data is so conspicuous, that we have included a variable (trackbar-function) calibration curve smoothing facility in all CalPal-programs. Nevertheless, to be able to visualize the smoothing effect, from case to case, still requires a fair amount of graphic processing. This requires, for example, a reference database that contains the different calibration curves, as well as the calibration raw data. These methods and databases are available in the CalPal-software (www.calpal.de. – WENINGER, 1986. – WENINGER – JÖRIS 2008).

As shown in Fig. 8, we have applied this procedure to a database containing N=44 well-known (LÜNING 2005. – STÄUBLE 2005) archaeological ^{14}C-ages assigned to the Central European Early Neolithic Linear Pottery Culture. In Fig. 8, the data are sequenced according to the detailed discussion of LÜNING 2005. This analytical sequence is based on a large number of individual site ^{14}C-analyses, on a variety of settlement models (e.g. STEHLI 1994), and on a long tradition of pottery seriation by Correspondence Analysis (e.g. STEHLI 1994. – STRIEHN 2000). The results are, briefly stated (i) the LBK begins c. 5500 calBC and ends c. 4950 calBC (ii) due to selective dating of 'old wood' (archaeological charcoal), the majority of ^{14}C-ages on samples for LBK-Phases 1–15 (5200–4950 calBC) have positions 'above' the INTCAL98 calibration curve (thin line connecting 68%-error bars), and (iii) due to prevailing large standard deviations it is difficult to extract further information from the data. But there is light in the dark: let us focus our attention on the position, relative to the INTCAL98-curve, of two AMS ^{14}C-ages measured by VERA-laboratory on human bone (VERA-1417: 6075 ± 35 BP; VERA-1516: 6115 ± 35 BP). These ^{14}C-ages are from burials in the cemetery of Flomborn, corresponding to ~ Stehli phase 4 of the LBK-sequence (LÜNING 2005). As shown in the inlay-graph, for this interval (5200–5160 calBC), there exist two groups of calibration raw-data. The first has ^{14}C-values ~ 6100 BP; the second has values ~ 6200–6280 BP. This wide spread of calibration curve raw data is not entirely satisfactory and leads to some conspicuous over-smoothing in the INTCAL04 calibration. The archaeological data at stake derive from the vicinity of what we call the 'LBK-Flomborn-wiggle', at ~ 5200 calBC (Fig. 8). Here, as in other subintervals of the LBK-window (5500–4900 calBC), the INTCAL04 calibration is constructed to run well beyond the majority of rawdata, and both curves (INTCAL98, INTCAL04) have clearly too small error envelopes. All these effects together, in the time-window 5500–4900 calBC, the calibration INTCAL04 is inadequate for wiggle-matching studies and can therefore not be recommended for use with single ^{14}C-ages.

THE STRATIGRAPHY OF ÁSSIROS TOÚMBA

Let us now turn out attention again to the stratigraphy of Ássiros Toúmba, where charred construction timbers from the excavations of Kenneth Wardle have provided the first direct near-absolute dates for the start of the Early Iron Age in Macedonia and by extension for the Protogeometric period in southern Greece. Before adressing these issues in further detail, below, the first thing we must do is to provide an independent check on the validity of the proposed dates. The data and methods at stake are described by NEWTON – WARDLE – KUNIHOLM 2005, with results that can be abbreviated as follows.

Following construction of a 104-year sequence of tree rings based on four seperate building timbers, a preliminary match with the Anatolian master chronology gives a probable cutting date of 1080 +4/-7 BC for trees associated with Phase 3 buildings and a date of 1070 +4/-7 for trees associated with Phase 2 buildings (NEWTON – WARDLE – KUNIHOLM 2005, 173). By radiocarbon wiggle matching (using INTCAL98), a date for the last preserved ring of the whole series of timbers and posts of Phases 2 and 3 of 1090 ± 22 calBC is obtained (NEWTON – WARDLE – KUNIHOLM 2005, 173).[16] Taking into account possible missing rings the authors propose a cutting date around 1070 BC for the post and the fallen timber of Phase 2, while c. 1080 BC is proposed for the two fallen timbers of the earlier phase 3.[17] The authors state that the finds of Phase 3 would thus fall into an interval between c. 1080 BC and 1070 BC.[18] We cannot check on the dendro-dates, but thanks to the radiocarbon data given by MANNING – KROMER – KUNIHOLM – NEWTON 2003 and additional dendro-data provided by NEWTON – WARDLE – KUNIHOLM (2005, 183 fig. 8), it is possible to run an independent test of the ^{14}C-based results.

As shown in Fig. 9, by application of the method of Gaussian Monte Carlo Wiggle Matching, we do not *immediately* confirm the cutting date of 1090 ± 22 calBC for the last trees in the sequence of wooden timbers and posts found in Phases 3 and 2, as proposed by NEWTON – WARDLE – KUNIHOLM 2005. As shown in Fig. 9, the Ássiros ^{14}C-sequence actually shows three alternative dates, that is (allowing 5 rings younger for given decadel sample width) ~ 1165 ± 10 calBC, ~ 1113 ± 10 calBC, and ~ 1083 ± 10 calBC (Fig. 9). We can nevertheless accept the proposed *dendro-based* cutting dates of 1080 BC +4/–7 denBC (Phase 3) resp. 1070 +4/–7 denBC (Phase 2). The argument is that the Ássiros ^{14}C-sequence fits nicely to a strong wiggle at ~ 1130 calBC, that shows up in the INTCAL04 calibration rawdata (Fig. 3). We have above already identified this wiggle in the Kastanás data (Fig. 6). The existence of this wiggle is convincingly demonstrated by the Heidelberg ^{14}C-data from Ássiros, notably due to one measurement (ASR 16: 3008 ± 22 BP, Lab Code not given: NEWTON – WARDLE – KUNIHOLM 2005, 183 fig. 8).

To conclude, although a definitive dendro-date is not available, we can confirm – using the published ^{14}C-ages – the near-absolute dates as proposed for Ássiros by NEWTON – WARDLE – KUNIHOLM 2005. However, this does not mean that we automatically accept Wardle's stratigraphic arguments, nor do we accept his conclusions as to the archaeological application of this date. Rather, we think it is most likely that the beams do not originally stem from the architectural phases in which they were found stratified and excavated. It is important to note that Phase 4, immediately preceding Phase 3, did not end in a conflagration, but was followed rather "peacefully" by the new buildings of Phase 3.[19] This means, it is theoretically possible and indeed very probable that construction timbers of abandoned and dismantled houses of

[16] NEWTON – WARDLE – KUNIHOLM 2005, 180; 183. – WARDLE – NEWTON – KUNIHOLM 2007, 493.

[17] NEWTON – WARDLE – KUNIHOLM 2005, 180–181. – WARDLE – NEWTON – KUNIHOLM 2007, 489–491.

[18] NEWTON – WARDLE – KUNIHOLM 2005, 181; 184. – WARDLE – NEWTON – KUNIHOLM 2007, 491.

[19] WARDLE 1989, 454–455. – IDEM 1997, 447 tab.; 450. – NEWTON – WARDLE – KUNIHOLM 2005, 174–176. – WARDLE – WARDLE 2007, 455 tab. 1; 471–472.

Phase 4, were re-used in constructing new houses of Phase 3. So far, neither a settlement plan nor single house plans of Phase 4 have been published, but apparently both phases had the same lay-out of buildings with the majority of walls being reused in the following Phase 3 (WARDLE 1989, 454–455).

Newton, Wardle and Kuniholm state that even if all the timbers were reused from Phase 4, "the start of the Iron Age in Macedonia would still be set before 1070 BC".[20] In our view, this conclusion is hardly warranted. In the case of such wood reuse from Phase 4 for Phase 3 and 2 buildings, the correctly established cutting date of 1070 BC only gives a *terminus post quem* for the erection of the Phase 4 buildings, not for their destruction or for the building events of the subsequent Phases 3 and 2. Phase 4 is altogether of uncertain duration.[21] The PG amphora is said to provide the relative chronology of Phase 3. However, regarding the introduction of the PG style into local Macedonian pottery production, a cutting date of 1070 BC only supplies a *terminus post quem* with an unknown number of years following. Even if the amphora had been produced during a rather developed stage of PG (see below), it would not be possible to conclude that PG had started before that *terminus post quem*.

All these observations put together, an 'old-wood' effect (in terms of wood recycling) for the beams found in Phase 3 is entirely possible.[22] Even for the following phase 2 one cannot exclude such a possibility, as the wooden posts were often mantled by the mud plaster of the walls.[23] Such a post inside a wall would not necessarily burn away in a fiery destruction, but might have been reusable. This is confirmed by historical sources and ethnographic studies on the fire combustion processes of timber-framed mud-brick houses.[24] If beams of Phases 4 and 3 were reused for Phase 2, such timber reuse also readily explains why the dendro-dates for Phases 3 and 2 are only 10 years apart.[25] In this context, it is especially interesting, that Wardle writes in a preliminary report: "The destruction of these buildings [i.e. of Phase 3] by yet another fire was only a temporary set-back to recovery, since the rooms were rebuilt with new timber supports set into parts of the walls which still stood … ".[26]

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20 NEWTON – WARDLE – KUNIHOLM 2005, 184 n. 20; repeated word by word in: WARDLE – NEWTON – KUNIHOLM 2007, 494 n. 67.

21 That duration may not have been very short. Deposits of phases 4 and 3 together reach a depth of more than 1 m in some places (WARDLE – WARDLE 2007, 471).

22 It is very interesting that the scholars working at Ássiros did regard the reuse of timbers as a convincing explanation for a discrepancy between historical-archaeological and dendrochronological/^{14}C-dates. However, they did so only with regard to LBA Phases 7 and 6. They use an argument very similar to the one outlined in the present article for Phases 4–2. In Phase 6 the building layout largely followed that of Phase 7, which was not destroyed by fire. So, timbers were available for re-use and the scholars conclude: "it is quite likely that these timbers are part of the construction of *Phase 7* and had remained in position or were reused in the rebuilding of Phase 6" (WARDLE – WARDLE 2007, 467). It is not clear, why they decide in a totally different way, when it comes to the later Phases 4–2. In the case of Phase 6 they hesitate from raising the date for the beginning of LH III C to the first half of the 13th century BC, as suggested by dendrochronological wiggle matching for three timbers from that building phase (1277 ± 25 BC, see IBIDEM). Their diverging chronological tables show that they remain undecided concerning the traditional date of c. 1200 for the start of LH III C (WARDLE – WARDLE 2007, 455 tab. 1. – WARDLE – NEWTON – KUNIHOLM 2007, 497 fig. 7). Indeed, the historical-archaeological chronology offers quite good arguments for leaving the start of LH III C Early around 1200 and connecting LH III B Middle with the first half of the 13th century BC (see below).

23 As becomes apparent for Phases 2 and 3 (WARDLE 1980, 254–255 fig. 15. – IDEM 1988, 377 fig. 1; 379 fig. 2. – NEWTON – WARDLE – KUNIHOLM 2005, 175 fig. 1. – WARDLE – NEWTON – KUNIHOLM 2007, 488 fig. 4), but also for the preceding LBA phases (WARDLE 1980, 241 fig. 7; 243 fig. 8. – WARDLE – WARDLE, 460 fig. 2).

24 HRUBY 2006, 29–31. On fire destruction of stone and mudbrick houses with flat mud covered roofs and wooden roof posts see GORDON 1953.

25 This small difference might then either be explained by burnt away rings or by partial reconstruction of buildings during the habitation period of Phase 4 or Phase 3.

26 WARDLE 1997, 452. – For the reuse of standing walls from Phase 3 into Phase 2 see also WARDLE 1989, 452.

It is further important to note that the PG amphora used to produce a relative chronological date for Phase 3,[27] cannot be closely dated in terms of the overall PG pottery chronology of the Aegean.[28] The vessel belongs to a central-north Aegean stylistic family, but no exact parallels are available from Macedonia, Troy or central Greece (especially regarding the single straight line placed between the circle systems, see JUNG 2002, 179). The Ássiros amphora might be Early PG, but could just as well belong to Middle PG, and maybe even to Late PG.

Apart from the stylistic/typological classification of that vessel, it does not seem unproblematic to us that some sherds of that (anyway far from complete) amphora come from Phase 2 contexts.[29] It is not-at-all safe to assume that the complex formation processes of a multilayered tell site only lead to upward re-deposition. All we can safely state is that there are sherds from the same vessel, found both in Phase 3 and in Phase 2 contexts. If the amphora was ascribed to Phase 2 rather than to Phase 3, a *terminus post quem* of 1070 BC for that Phase 2 would support a rather traditional absolute chronology, as we shall see in the following discussion. Unfortunately, at Ássiros there is no other wheel-made PG pottery to offer additional contextual data. Painted Mycenaean pottery from Phase 5 is said to date to LH III C, while the small linear-decorated fragments from Phase 4 are worn and taken to be residual.[30] None of the pottery of Phases 5 and 4 has yet been illustrated. For Phase 4 channeled hand-made pottery and wheel-made Grey Ware are classified as new Iron Age types of pottery.[31] However, a comparison with the large quantities of material from the vertical stratigraphies of the tell sites at Kastanás and Thessaloníki Toúmba shows that both classes were first introduced during the later LH III C phases to the repertory of the Central Macedonian pottery workshops.[32] For instance, channelled hand-made pottery is securely attested in Level 13 at Kastanás, i.e. LH III C Developed–Advanced.[33]

At Ássiros the only wheel-made pot, which is ascribed to Phase 3, is the amphora we are discussing. From Phase 2 wheel-made pottery is said to be totally absent – apart from so-called "Mycenaean survivals"[34]. Eight handmade pots are published from Phase 3.[35] One is a fully preserved amphora with facetted vertical handles.[36] While its incised decoration can be easily attributed to the LBA tradition with parallels in Level 14b (LH III C Early) at Kastanás (HOCHSTETTER 1984, pls. 40:1; 51:13), the facetted handles are characteristic for the later Levels of the EIA, but they are first found in Level 13 at Kastanás (LH III C Developed–

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[27] WARDLE 1997, 448; 455 fig. 3:2. – NEWTON – WARDLE – KUNIHOLM 2005, 176; 177 fig. 2; 184–185; 190 pl. 2. – WARDLE – WARDLE 2007, 454–455 tab. 1; 472–473. – WARDLE – NEWTON – KUNIHOLM 2007, 489; 492 pl. 2; 493 fig. 6; 494–497 fig. 7.

[28] Probably in order not to present an even more unexpected absolute date the authors chose to opt for an Early PG date for the amphora – raising the absolute date for the start of PG to c. 1100 BC. But – as they themselves admit (NEWTON – WARDLE – KUNIHOLM 2005, 185. – WARDLE – NEWTON – KUNIHOLM 2007, 495) – 1120 BC might be also possible, if the amphora is MPG rather than EPG. One might go even further, if everything depends on only that one vessel.

[29] NEWTON – WARDLE – KUNIHOLM 2005, 184 n. 21. – WARDLE – NEWTON – KUNIHOLM 2007, 494 n. 68.

[30] WARDLE 1997, 448. – WARDLE –WARDLE 2007, 469; 472.

[31] WARDLE – WARDLE 2007, 471–472. In earlier reports Grey Ware was mentioned for Phase 1 (WARDLE 1980, 260 with fig. 19:54. – IDEM 1997, 449).

[32] For the stratigraphic evidence concerning wheel-made Grey Ware see JUNG 2007. The sequence of Thessaloníki Toúmba is especially relevant for this class, see ANDREOU in the present volume.

[33] HOCHSTETTER 1984, 188–194 pls. 62:7; 64:5,10; 71:2; 73:10. Therefore, it is incomprehensible that WARDLE – NEWTON – KUNIHOLM (2007, 489) state: "The stratigraphy [of Kastanás] does not permit us to associate the channelled ware *specifically* with either Mycenaean or Protogeometric pottery and a Mycenaean date for its introduction at this site is hard to support". On the contrary, the stratigraphy shows clearly that the production of this class started during the middle phases of LH III C and was intensified in the following Levels 12, 11 etc.

[34] WARDLE 1980, 260. – IDEM 1997, 448.

[35] WARDLE 1997, 451 fig. 1:2–7; 453 fig. 2:5; 455 fig. 3:5. – WARDLE – NEWTON – KUNIHOLM 2007, 486 fig. 3:1,2.

[36] WARDLE 1989, 454 pl. 68e. – IDEM 1997, 455 fig. 3:5. – WARDLE – WARDLE 2007, 472 pl. 18.

Advanced).[37] Another four pots illustrated from Phase 3 are steep-sided bowls with wishbone handles. In one case the flattened handle terminal shows a marked carination (WARDLE 1997, 451 fig. 1:2). Parallels for such bowls with vertically placed wishbone handles can be found at Thessaloníki Toúmba from LBA Phase 4 onwards.[38] Carinated wishbone handles were thought to be exclusive to the Early Iron Age (starting at Kastanás, Level 10),[39] but they are found in Phase 4 at Thessaloníki Toúmba[40] and at Áyios Mámas (Prehistoric Olynthus) throughout the Late Bronze Age.[41] The sixth illustrated vessel from Phase 3, a cut-away-neck jug with a step-like rim and neck shape (WARDLE 1997, 453 fig. 2:5), could be more decisive in chronological respect, as this type is not securely attested earlier than Level 11 (MPG) at Kastanás (HOCHSTETTER 1984, 53 fig. 12 [types 1b–1d]; 55–56). However, a fragment preserving shoulder and facetted handle of a closed vessel from a mixed context of Levels 13 and 14a at Kastanás can very probably be reconstructed as a cut-away-neck jug of that type.[42]

The final two published handmade sherds from Ássiros Phase 3 show channelled decoration (WARDLE – NEWTON – KUNIHOLM 2007, 486 fig. 3:1,2). One is a carinated bowl with channelling at the carination. The other one is a closed vessel with fine channelling on the belly. They find parallels at Kastanás from Level 13 onwards (HOCHSTETTER 1984, 188–194 pls. 64:5,10; 82:5,7; 110:8; 112:3; 117:6,9,10).

Thus, the handmade pottery of Phase 3 does show characteristics which, in central Macedonia, are especially common during the early Iron Age. However, as comparisons with other Central Macedonian tell stratigraphies at Kastanás, Thessaloníki Toúmba and Áyios Mámas (Prehistoric Olynthus) reveal, none of the few published vessels must necessarily be dated to the PG period (the cut-away-neck jug being the only possible exception).

An iron double axe was found in a large pit, which could not be securely assigned to either Phase 3 or 2, although an assignation to Phase 3 was preferred on the background of the settlement plan as a whole.[43] That heavy iron implement should probably rather be dated to PG than to Submycenaean or LH III C.[44]

To sum up the evidence from Ássiros, the redating of the start of the Greek Early Iron Age at this site is based on one single, partially preserved PG vessel scattered through two consecutive settlement phases, which are dated by four timbers that could have been reused from earlier buildings. This does not, however, imply that the dendro-dates from Ássiros are not useful. If the dated timbers were reused construction material from Phase 4 and the PG amphora is EPG in date, from these results it follows that the end of Submycenaean must be sought sometime during the 11th century BC – clearly much later than assumed by Kenneth Wardle.

37 HOCHSTETTER 1984, pls. 73:10 (even from a mixed context of Level 13 and the earlier Level 14a); 75:4 (from Level 12, LH III C Advanced – EPG, stylistically quite similar to the Ássiros piece, also with regard to the incised band below the rim); 112:2; 117:13 (also similar to the Ássiros amphora); 140:2; 141:5; 156:11.

38 PSARAKI 2004, pls. 6.45:KA 969; 6.47:KA 870/874. – ANDREOU – PSARAKI 2007, 409 fig. 11:KA 969,KA 870/874. The handles of these bowls are not carinated.

39 Level 10 dates to LPG (HOCHSTETTER 1984, 94 fig. 24:11b; 98; 100 pl. 115:1,2; 147:1,2).

40 PSARAKI 2004, pl. 6.45:KA 421; 6.46:KA 1624. However, these handles are less massive than the one from Ássiros. – Phase 4 of Thessaloníki Toúmba covers the first half of the period LH III C, but can now be divided into several stratigraphic sub-phases (see ANDREOU this volume). Phase 2 can be very well paralleled with the end of Level 12 of Kastanás and similarily includes the EPG phase (see JUNG – ANDREOU – WENINGER this volume).

41 HOREJS 2007, 103 fig. 48; 104 fig. 49; 332 pl. 41:5613,5619; 58:5608; 84:5599.

42 HOCHSTETTER 1984, pl. 73:10. – Alternatively, it could belong to an amphora like the one from Ássiros (see n. 36). The orientation of the sherd has to be changed in either case.

43 WARDLE 1987, 320 pl. 51b. – WARDLE – WARDLE 2007, 473.

44 Iron trunnion axes are known from LPG tombs at Athens and Lefkandí, while an iron double axe was found in a SPG tomb, again at Lefkandí (LEMOS 2002, 122).

THE ABSOLUTE CHRONOLOGY OF THE SUBMYCENAEAN PHASE

Pottery of Submycenaean type is present at Kastanás, Level 12, e.g. monochrome deep bowls, with straight and carinated profile, decorated with a reserved outer zone carrying a single or double horizontal zigzag (Fig. 10:1,4,7), for which parallels can be found mainly in Submycenaean (Fig. 10:2,3,5,8) and partly also in EPG contexts in central and southern Greece (JUNG 2002, 103–104, 226 pls. 23:259; 24:272,274 with bibliography).[45] However, we unfortunately have no absolute dates for that phase from the site. But we can derive such dates from the West, making use of the tight relative chronological connections between the Aegean and Italy (JUNG 2006).

The destruction horizon of the settlement of Rocavecchia at the Adriatic coast of Apulia contained hundreds of broken pots lying in situ on house floors. The indigenous hand-made pottery can be dated to an advanced stage of Final Bronze Age 2 (FBA 2), while a number of wheel-made pots of Aegean style, especially monochrome deep bowls with zigzag motifs in the reserved outer zone (Fig. 10:6,9), provide a synchronism with the Submycenaean phase of the Greek mainland (GUGLIELMINO 2005, 643 pl. 167:a,1.2. – JUNG 2006, 153–165 pl. 12:1–7).[46] Some of the monochrome deep bowls show the same straight profile and reserved outer zone with single or double zigzag as the aforementioned vessels from Kastanás (IBIDEM, pl. 12:2,3).

Apart from the pottery scattered on house floors, there are two rich bronze hoard finds (MAGGIULLI in press), which help to fix the Rocavecchia destruction towards the end of FBA 2 and connect it with closed find complexes from central and northern Italy. Among the chronologically important types there are e.g. twisted symmetrical bow fibulae (Fig. 11:2) from hoard 2 (IBIDEM, fig. 1:15b–35,77). This type is not known earlier than Submycenaean in the Aegean (Fig. 11:1; see JUNG 2006, 190 pls. 16:6; 18:5–6,8; 19:5,6. – RUPPENSTEIN 2007, 218[47], pls. 30:Gr. 136/10; 33:Gr. 143/3. – DEGER-JALKOTZY this volume), while in Italy it first appeared in FBA 2 contexts (Fig. 11:3; see JUNG 2006, 191 pl. 14:1,2), e.g. in the urnfield cemeteries of the Veneto (COLONNA 2006, 90–92: types 20–22bis; 255 pl. 31:5–9; 256–258 pl. 32–34). The production of those fibulae seems to have started during a later stage of FBA 2 and continued into FBA 3 (IBIDEM, 182, 187 fig. 3; 193, 199; fig. 1). Another interesting type of hoard 2 of Rocavecchia is the symmetrical bow fibula with two knots, which are shaped as groups of thin rings (MAGGIULLI in: SETTIS – PARRA 2005, 312–313 cat. no. II.208. – EADEM in press, fig.). This shape of bow knots is not found on LH III C bow fibulae in Greece, it first appears at two fibulae from Submycenaean tombs in the Kerameikos (MÜLLER-KARPE 1962, 86 fig. 4:7; 88 fig. 6:7. – RUPPENSTEIN 2007, 218: type 2b). In Italy it is attested in a burial context at Campo del Fico in Latium (DELPINO 1987, 17 figs. 6–7; 27, 30 fig. 16:5; 35 no. 5), dated to FBA 2 (PACCIARELLI 2000, 212–213 fig. 120). In the Aegean symmetrical bow fibulae with semicircular bow and two knots do not appear in closed contexts of LH III C date.[48] In Italy this type of bow fibulae seems to have been in use since FBA 2 or 3 (JUNG 2006, 156 n. 1096).

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[45] Note that it is often not easy to differentiate between tight wavy line and true zigzag. Even on one and the same vessel the motif may change from a more wavy to a more jagged ondulation.

[46] One ^{14}C-date is published from that settlement phase: LTL 1872A (on beans): 2876 ± 60 BP (CALCAGNILE – D'ELIA – QUARTA in: PAGLIARA *ET AL.* 2007, 357 fig. 21). Unfortunately, the only date from the preceding settlement phase is a clear outlier in contradiction to its stratigraphical position in the whole sequence (IBIDEM, 356). Thus, this single date from the FBA 2 destruction cannot be used in the present argument.

[47] The stratified LH III C examples quoted by RUPPENSTEIN (2007, 219–220) either have a different bow shape (rectangular instead of semicircular at Peratí, chamber tomb 74, cf. JUNG 2006, 190–192 pl. 19:3) or are secondarily distorted (Árgos, tumulus on the Kantzávelos plot, inv. no. 10105 – personal examination thanks to the kind permission of Chrístos Piterós).

[48] LH III C bow fibulae with knots are asymmetrical with the bow raising vertically from the catch plate and being slightly bent at the point, where its semicircular part begins, see JUNG 2006, 192–194. For symmetrical bow fibulae with knots see IBIDEM, 156, n. 1096.

By means of bronze objects the Italian Final Bronze Age can be synchronized across the Alps with the Urnfield phases in Switzerland and southern Germany. At the beginning of Ha B1 (Ha B1 early) a new series of lake-side settlements was founded on the shores of the Swiss and southern German lakes.[49] Those lake-side sites can be exactly dated by dendrochronology. The wooden posts of the houses provide *termini post quem* for the first phase of these settlements with dendrodates between 1071 and 1034/35. The rich finds from Level 3 at Hauterive-Champréveyres at Lake Neuchâtel with dendro-dates from cutting phases between 1054 and 1037 denBC may serve as an example.[50] The relevant bronze repertory which belongs to that phase has parallels in FBA 2 in Italy. It includes winged axes with wings placed close to the neck (Fig. 12:3; see RYCHNER-FARAGGI 1993, 36, 38, pls. 24:2–6; 25:3) and tanged knives with bulging back and a loop at the tang end (Fig. 12:5,6; see IBIDEM, 40 pl. 30:5–10). The same type of tanged knife is found in the hoard of Poggio Berni (Fig. 12:4) in Emilia Romagna, north-eastern Italy (MORICO 1984, 23–25 fig. 4:15. – BIANCO PERONI 1976, 58 no. 257 pl. 31:257). The winged axes find close parallels in the central Italian hoard of Monte Primo (Fig. 12:1,2), Marche region (PERONI 1963, I.7.8-[3] nos. 9 and 10;[51] 8-[4] no. 16; 8-[8] nos. 42 and 43). While the first hoard is dated only roughly to FBA 1/2 (containing types of both phases) by Gian Luigi Carancini and Renato Peroni, the second one is dated to FBA 2 in their seriation of hoard finds from continental Italy (CARANCINI – PERONI 1999, 18–19 pl. 29). The winged axes of Monte Primo are eponymous for a whole type, which, as a result of that hoard find seriation, can be taken as characteristic for FBA 2 (IBIDEM, 62 no. 9 pls. 30:9; 32:9).

Another knife shape present at Level 3 of Hauterive-Champréveyres has a bulging back and a tang without loop (form 2: RYCHNER-FARAGGI 1993, 41 fig. 36). Some of the specimen can be closely compared to two fragmentary knives from the 4th hoard found at Frattesina (cf. IBIDEM, pls. 31:8; 32:4 with SALZANI 1987, 219 nos. 9 and 10; 226 fig. 1:9,10), which based on the rest of the material can again be dated to FBA 2.

Amber beads of Allumiere type were also found at Hauterive-Champréveyres (Fig. 11:9). Again they are confined to Level 3 (RYCHNER-FARAGGI 1993, 66, pl. 124:6,7), which makes them relevant for the synchronisation with the Italian relative chronological sequence. In northern Italy amber beads of Allumiere type are present at Bismantova tomb XXXI, which according to the overall seriation of north Italian cemeteries by Cecilia Colonna is dated to Phases I/II, that is FBA 2 (COLONNA 2006, 129, 177, 191 fig. 5; 193, 199, 201; fig. 1). Several examples of that type were also found in the Campo del Fico burial of FBA 2 date (Fig. 11:7,8), which yielded the bow fibula mentioned above (DELPINO 1987, 18 fig. 9; 27, 32 fig. 18:7–12; 35–36 nos. 7–12).

The significance of certain bronze types in the tombs of the Narde cemetery belonging to the settlement of Frattesina for the comparative Italian–Swiss chronology has already been highlighted by Christopher Pare (PARE 1998, 314–315 fig. 8).[52] An incised pin with globular head and two globules below from tomb 227 (Fig. 11:4; see SALZANI 1989, 16, 38 fig. 16:10) belongs to the most important finds in this respect. It has no parallels in other north Italian tombs (COLONNA 2006, 82–83, 249 pl. 25:2), but is attested with several examples in Level 3 of

[49] This phase is characterised by a mixture of types conventionally thought to be characteristic for Ha A2 and others representing the succeeding phase Ha B1 in the traditional relative sequence. Therefore, it was suggested to classify the repertory of this phase as a transitional Ha A2/B1 style or as early B1 (RYCHNER 1995, 457, 460, 483). The last suggestion prevailed (DAVID-ELBIALI – DUNNING 2005, 151–156. – TRACHSEL 2004, 37–39).

[50] See also dendrochronologically dated bronzes from the settlements at Greifensee-Böschen (with dates between 1048 and 1042 denBC), Zug-Sumpf (with dates between 1056 and 994 denBC) and Zürich-Großer Hafner, Level 3 (1055 denBC): DAVID-ELBIALI – DUNNING 2005, 145–146; 152–156 fig. 3; 180–181 pls. 2–3.

[51] This one is slightly different from the Italian examples in having a more trapezoid blade.

[52] PARE 2008 came to broadly similar conclusions when comparing Italian finds to the Swiss assemblages.

Hauterive-Champréveyres (Fig. 11:5,6; see RYCHNER-FARAGGI 1993, 47–49 fig. 43, pl. 55:1–6).[53] In Colonna's seriation Narde tomb 227 belongs to her Phase II and thus to a late stage of FBA 2 (COLONNA 2006, 173, 189–192 fig. 5; 199–201 fig. 1), which means it should be contemporary with the destruction of Rocavecchia and the Submycenaean phase in the Aegean. Another interesting pin type is attested in tombs 142 and 168 of the Narde cemetery (SALZANI 1989, 14, 34 fig. 12. – IDEM 1990–91, 137, 185 fig. 38:6). Those pins have a double-conical head with the upper conus being higher than the lower one. They bear no decoration. According to Colonna and like the preceding type these pins are typical for her phase II, i.e. a late stage of FBA 2 (COLONNA 2006, 75, 172, 187 fig. 3; 244 pl. 20:1,4; fig. 1: SP 16A). At Hauterive-Champréveyres they are characteristic for Level 3 (RYCHNER-FARAGGI 1993, 48 fig. 45, pl. 63:8,10,14).

From the above discussion it follows that Level 3 of Hauterive-Champréveyres can be synchronised with Italian FBA 2, and most probably only with its later part. Clear types of FBA 3 only appear in the following phase of the Swiss settlements with dendro-dates after 1000 denBC (PERONI – VANZETTI 2005, 61, 80 pl. 13. – PACCIARELLI 2005, 83–84). As best examples pins with heads "à céphalaire" from Level 03 at Hauterive-Champréveyres are named (RYCHNER-FARAGGI 1993, 47–48 fig. 44, pls. 57:1,8,10; 58:2–5,7,9,11,14; 59:6,9,12,14), because they find a good parallel at the necropolis of Morano sul Po, tomb 1/95 (VENTURINO GAMBARI – LUZZI 1999, 113–114 fig. 96:6. – COLONNA 2006, 83, 249 pl. 25:11). This tomb is dated by Colonna to her phase III, i.e. FBA 3 (COLONNA 2006, 175, 199, 211; fig. 1).

Thus, we get a date around 1040 for the end of the Italian FBA 2 and Greek Submycenaean. Additional data come from Italy itself, from Tuscany, from a pile dwelling settlement at Livorno-Stagno. This Final Bronze Age settlement was situated in a brackish lagoon environment, which helped to preserve parts of wooden house constructions. The Bronze artefacts of the settlement can be dated to FBA 2, while the pottery belongs to FBA 2 and the beginning of FBA 3.[54] Seven vertical posts of elm wood were sampled for dendrochronological analysis on a local sequence comprising 70 tree-rings. Two cutting phases, 25 years apart from each other, could be determined due to the presence of a "Waldkante" in two samples. Four radiocarbon dates measured at Heidelberg allow a dendrochronological wiggle match of that sequence.[55]

The application of Gaussian Wiggle Matching to the floating Livorno ^{14}C-age sequence (Fig. 13) places the youngest dated decadel tree-ring block at 1092 ± 25 calBC (68%) or 1127–1025 calBC (95%). This results in a 5 yr younger cutting date, that is 1097 ± 25 calBC (68%) or 1122–1020 calBC (95%). This age-fitting for the Livorno tree is not as stable as we would like. As shown in Fig. 13, the distribution of best-fitting calendric ages (achieved for N=10000 iterations; with assumed cutting error σ ±3 rings and assumed Gaussian interlaboratory offset σ ± 10 yrs ^{14}C-BP) is not entirely Gaussian. Next to the major age value with highest probability (~1092 ± 25 calBC), there exist other regions (~ 1020–1060 calBC, ~ 1100–1130 calBC, even ~ 1180 calBC) that must also be seriously taken into consideration. Due to their extremely seldom occurrence in the Monte Carlo simulation, we may decide that the few high readings ~ 1180 calBC are unrealistic. What then remains, is that 1130 calBC can be taken as clear *terminus post quem* for the beginning of FBA 3. In particular, the younger dating of the Livorno sequence ~ 1060–1020 calBC (clearly visible in Fig. 13 as an extended and therefore highly reproducible peak in dating probability, perhaps only scaled by chance to somewhat lower probability values) agrees very well with a large number of archaeological synchronisms,

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53 More examples were found in other Swiss lake settlements with analogous dendro-dates, which allows the conclusion that the type went out of use during the second half of the 11th century BC (TRACHSEL 2004, 33–34 fig. 15: type 3).

54 ZANINI 1997a. – ZANINI – MARTINELLI 2005, 148–149. – For the relative chronological date see also PACCIARELLI 2000, 44–45 fig. 23:C. – IDEM 2005, 83.

55 ZANINI – MARTINELLI 2005, 147, 149, 151 tab. 2; 152 fig. 5.

absolutely dated by an extended set of dendro-dates for exactly this window (~ 1055–1035 calBC) from four Swiss sites (Hauterive-Champréveyres, Level 3; Greifensee-Böschen, Zug-Sumpf and Zürich-Großer Hafner, Level 3).

Due to the greater quantities of archaeological finds and dendro-dated samples the Swiss dates should be given greater weight than the central Italian ones. By combining Swiss and Italian dates, the end of FBA 2 may now be narrowed down to the time between c. 1070 and 1040 BC. The Rocavecchia synchronism of the end of FBA 2 and Submycenaean allows us to transfer these dates to the Aegean, where we propose an end of Subymycenaean and a beginning of PG around 1070/40 BC, at the maximum 10 to 20 years earlier than Desborough's traditional date of 1050 BC. This is in near-perfect agreement with the traditional historical-archaeological data of the LH III C phases according to the ^{14}C sequence of Kastanás. As a result we would like to make a new proposal for the absolute chronology of the end of the Greek Late Bronze and the beginning of the Early Iron Age (Fig. 14).

The left column gives an impression of the relative phase length of Late Mycenaean pottery phases, by the number of settlement horizons corresponding to each ceramic phase at Tiryns, Lower Citadel (according to PODZUWEIT 2007).[56] Columns 2 to 4 summarize our anchors for the absolute chronolgy of the 12th to 10th centuries BCE. The proposal in column 5 is the result of combining the evidence of columns 1 to 4.

The only historical-archaeological date, which can be securely linked to the Aegean pottery chronology is the destruction of the Syrian coastal sites of Ugarit and Tell Kazel. Both sites show clear signs of violent destructions, and both destruction levels contain Mycenaean-type pottery, of which the typologically latest vessels cannot be dated earlier than LH III B Final. Most probably the latest Mycenaean-type pottery from both sites dates to the beginning of LH III C Early (MONCHAMBERT 2004, 269–300, 321–322. – MOUNTJOY 2004. – JUNG 2008, 191–196). The destructions of those two Syrian cities are best explained as resulting from attacks by enemies coming from the sea and referred to in texts found at Ugarit (KLENGEL 1992, 149–151) and, most important, in a dated inscription from Egypt. That is the famous inscription from pharaoh Ramesses' III temple at Medinet Habu, which is dated to his regnal year 8. It mentions a coalition of enemies coming from some Mediterranean islands (most probably in the Aegean), who try to attack Egypt. These people, referred to in the scholarly literature as Sea Peoples, are said to have destroyed various countries including Carchemish, i.e. the region of northern Syria, where Ugarit is situated. The same inscription mentions that the aggressors set up a camp in Amurru before moving on, towards Egypt. The largest Late Bronze Age tell in the region of Amurru and therefore probably its capital is Tell Kazel in Syria. The year 8 inscription states that Amurru was destroyed by that peoples coalition, and a total destruction is also reported in another inscription from Medinet Habu dated to year 5 of Ramesses.[57] Thus, the Medinet Habu inscriptions set a number of *termini ante quem* for the destructions of Ugarit and Amurru. Today there seems to be considerable agreement among the Egyptologists as to the regnal period of pharaoh Ramesses III. According to the different reconstructions of the pharaonic chronology his year 8 is calculated to be 1180 (KRAUSS 2007, 187), 1177 (KITCHEN 2000, 49) or 1176/75 (VON BECKERATH 1997, 106, 190) BCE, while his 5th year would be 1183, 1180, 1179/78 BCE. These are the lowest possible *termini ante quem* for the start of LH III C Early. But the dating range can be further narrowed down at Ugarit with the help of an Egyptian letter found in the House of Urtenu.

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[56] Note that there are differences in labelling some of the horizons between Klaus Kilian's proposal and the one by Christian Podzuweit. Here, Podzuweit's proposal is used, as this forms the basis for the pottery chronology of the site.

[57] However, it is debated amongst egyptologists, whether the year 5 inscription reflects a real historical event or is rather an anachronistic anticipation of the processes described under the heading "year 8" (CIFOLA 1988, 291).

That letter (written in Akkadian) was sent by Bay (FREU 1988), pharaoh Siptah's chancellor. A recently discovered new document from Egypt states that Bay was executed as a traitor in Siptah's regnal year 5 (GRANDET 2000). According to current calculations Siptah reigned from 1197 (KRAUSS 2007, 187) or 1194/93 (VON BECKERATH 1997, 105, 190. – KITCHEN 2000, 49). This means that Bay's execution occurred in 1193 or 1190/89. This date sets a *terminus post quem non* for the posting of the letter from the House of Urtenu. Thus, LH III C Early must have begun before the time period between 1197 and 1175, the extreme dates offered by the discussed written sources.

Another kind of *terminus ante quem* is offered by the ^{14}C-dates of Kastanás, Level 13, which, as discussed above, centre around the downward wiggle ~ 1180 calBC (Figs. 4 and 6) The buildings of this Level were erected during LH III C Early or Developed.[58] The dating uncertainty of its beginning is due to the very fragmented material from the Level itself and to the scarcity of datable sherds from the preceding Level 14a. Level 14b can be assigned a more secure date to LH III C Early and most probably to an early stage of that phase (JUNG 2002, 222–224). Therefore, the three ^{14}C-dates with readings around 1180 calBC give a *terminus ante quem* for a somewhat developed stage of LH III C Early or for IIIC Developed. The real building event cannot have happened much later than 1180, say between 1180 and 1170 BCE, because two of the three dates are on shortlived animal bones. It has to be taken into consideration that LH III C Early cannot have been a very short phase, because it is represented by two building horizons inside the Lower Citadel of Tiryns (PODZUWEIT 2007, 324–325) and in the northwestern and northeastern quarters of the town (MARAN – PAPADIMITRIOU *ET AL.* 2006). On that basis, the ^{14}C-dates from Kastanás can be combined with the Near Eastern historical dates in an entirely satisfactory manner. If the destruction of Ugarit and Amurru occurred towards the beginning of the time window 1197–78 BCE, the Kastanás dates do not force us to push back the start of LH III C Early much into the 13th century. In this way, one can confirm a very conventional date for the end of the Mycenaean palace system of c. 1210/1200 BCE.[59]

The Kastanás *terminus ad quem* of ~1130 calBC for a certain moment during the course of LH III C Advanced (as extracted from the Level 12 dates), is furthermore in good agreement with the calculated end date of 1070/40 BCE for the Submycenaean phase, because (i) LH III C Advanced was a lengthy settlement phase at Tiryns (cf. PODZUWEIT 2007, 325–326) and (ii) Submycenaean does not seem to have been a very short phase judging by the Kerameikos tomb evidence (RUPPENSTEIN 2007, 269).[60] Therefore, on balance we have assigned a longer time period to Submycenaean than to LH III C Late.

CONCLUSIONS

Most important, we conclude there exists near-perfect agreement (with remaining errors on the scale of a few decades) between the traditional historical-archaeological dating of the Aegean Late Bronze Age – for all phases between LH III B Early and Submycenaean – and the tree-ring calibrated ^{14}C-data as obtained from Kastanás. As a result of chronological fine-tuning of finds from the sites of Kastanás, Ássiros, Tiryns, Tell Kazel and Ugarit, and by transfer of dendro-dates from Switzerland via Italy to the Aegean, we make a new proposal for the absolute chronology of the end of the Greek Late Bronze and the beginning of the Early Iron Age (Fig. 14).

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58 They were destroyed during LH III C Advanced.

59 This date is also consistent with the ^{14}C-dates of the earlier Levels of Kastanás, which we do not discuss in detail in the present paper (but cf. JUNG – WENINGER 2004, 216–217, 224).

60 However, the 100 year duration discussed by RUPPENSTEIN (2007, 269) for the Submycenaean phase cannot be confirmed by our present study, even if his stage IV (Submycenaean/Protogeometric Transitional Style) is incorporated into the EPG phase.

We further conclude that the long-standing dating-discrepancies at Kastanás can be explained by a combination (stacking) of different effects, mainly: (i) measurements performed on 'old-wood' samples, (ii) major distortion of calibrated ages for short-lived (~ 1–4 yr old animal bone) samples by application of an inadequate (10–20 yr) tree-ring calibration curve, and (iii) inadequate (over-smoothed) construction of tree-ring calibration curves (both INTCAL98 and all the more INTCAL04), based on an inadequately low tree-ring sample density. This explanation is demonstrated by pairwise comparisons of the archaeological data with the INTCAL04 curve, the archaeological data with INTCAL04 raw data, as well as the INTCAL04 curve with INTCAL04 raw data.

The inescapable corollary of this work is that the Radiocarbon Community must seriously consider undertaking a major research program, directed at establishing a Holocene ^{14}C-age calibration based on a continuous sequence of annual samples. This annual ^{14}C-age calibration would supply to archaeologists, on a world-wide scale, the widely requested chronological control over cultural events and processes, including the Aegean Late Bronze Age under study in the present paper, with achievable decadel dating precision.

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Sample A (Wood)	> 46000 BP	47520 (complex) BP
Sample B (Wood)	> 45000 BP	47780 (complex) BP
Sample C (Turbidite)	18160 ± 100 BP	18173 ±11 BP
Sample D (Wood)	4523 ± 26 BP	4508 ± 3 BP
Sample E (Humic acid)	(not processed)	11778 ± 7 BP
Sample F (Wood)	4459 ± 30 BP	4508 ± 3 BP
Sample G (Barley)	111.42 ± 0.34 pMC	110.69 ±0.09 pMC
Sample H (Wood)	2208 ± 35 BP	2232 ± 5 BP
Sample I (Cellulose)	4396 ± 37 BP	4485 ± 5 BP
Sample J (Barley)	111.63 ± 0.35 pMC	110.69 ±0.09 pMC

Tab. 1 Köln Radiocarbon Laboratory Intercomparison Results. Fourth International Radiocarbon Study (FIRI-2000)

VIRI Sample	University of Cologne Results	VIRI preliminary consensus values (Standard Radiometric)
Sample A (Barley)	109.620 ± 0.31 pMC	109.1 ± 0.94 pMC
Sample B (Cereal)	2771 ± 28 BP	2820 ± 3.3 BP
Sample C (Barley)	111.220 ± 0.36 pMC	110.7 ± 0.04 pMC
Sample D (Cereal))	2819 ± 29 BP	2836 ± 3.3 BP

Tab. 2 Köln Radiocarbon Laboratory Intercomparison Results. Fourth International Radiocarbon Study (VIRI 2007/2008) presently underway

Lab code	Excavation number	Level	Material	Archaeological context; time position in phase	Libby age [^{14}C-BP]	δ^{13}C‰ PDB
KN-5226	77/5198	6	3 mandibulae, pig; 1 maxilla, pig; 1 pelvis, pig; 1 pelvis, cattle; 1 femur, cattle	AC–AE 55–57: *Südgasse* (South Lane); beginning of phase	2765 ± 30	–17.29
KN-5230	78/2552	9	radius, cattle	X–Y 42–43: probably first half of phase	2833 ± 23	–17.94
KN-5231	79/40036	10	2 x radius+ulna; 1 radius; all cattle	Z–AB, 51–52: beginning of phase	2800 ± 20	–13.81
KN-5234	79/40114	11	2 tibiae, cattle; 1 metatarsus, red deer	AK–AG 51–52: *Straße zwischen Zentral- und Seitenhaus* (Street between Central and Lateral House); middle of phase	2917 ± 29	–15.03
KN-5236	79/40230	12	1 metatarsus, red deer; 1 tibia, fallow deer	AK–AL 49–52: Loggia, Raum 2 (Loggia, room 2); second half of phase	2970 ± 30	–20.39
KN-5239	78/1486	13	1 metacarpus, red deer; 1 tibia, red deer; 1 pelvis, cattle	V–W 40–43: *Straße südlich des Flechtwandhauses* (Street south of Wattle-and-Daub House); beginning of phase	2892 ± 28	–20.95
KN-5368	78/1943	16	radius, fallow deer	P–Q 43–44: *Pithoshaus, Pithosgrube* (Pithos House, pit of pithos); –	3080 ± 30	–21.30

Tab. 3 New (previously unpublished) ^{14}C-dates on animal bones from Kastanás

No.	Lab. Code	Kastanás Level	Material	^{14}C-Age [^{14}C-BP]	δ^{13}C	Expected Age [hist./BC]	Delta [calyrs]	Sum [calyrs]
1	KI-1567	6	charcoal	2930 ± 160	–23.5	735		
2	KN-2578	6	charcoal	2730 ± 95	–	740		
3	KN-2577	6	charcoal	2920 ± 120	–	745		
4	KN-5226	6	bone ●	2765 ± 30	–17.29	750		
5	KI-1782	8	charcoal	2920 ± 55	–23.7	775		
6	KN-2579	8	charcoal	3030 ± 55	–	778		
7	KN-5229	8	bone ●	2795 ± 20	–14.02	782		
8	KN-5228	8	bone ●	2822 ± 24	–15.08	785		
9	KN-1783	8	charcoal	2880 ± 70	–25.1	790		
10	KN-5227	8	bone ●	2881 ± 29	–13.65	795		
11	KN-2580	8	charcoal	2990 ± 50	–	790		
12	KN-5230	9	bone ●	2833 ± 23	–17.94	850		
13	KN-2581	9	charcoal	2980 ± 50	–	865		
14	KN-5233	10	bone ●	2780 ± 35	–20.28	910	0	0
15	KN-5232	10	bone ●	2805 ± 35	–17.69	920	10	10
16	KI-1785	10	charcoal	2920 ± 46	–22.3	925	5	15
17	KI-1784	10	charcoal	2860 ± 65	–25.1	930	5	20
18	KN-5231	10	bone ●	2800 ± 20	–13.81	933	3	23
19	KN-5063	10	charcoal	2743 ± 34	–25.56	935	2	25
20	KN-5235	11	bone ●	2955 ± 26	–13.48	945	10	35
21	KN-5234	11	bone ●	2917 ± 29	–15.03	965	20	55
22	KN-2583	11	charcoal	2750 ± 110	–	995	30	85
23	KN-2582	11	charcoal	3010 ± 50	–	1000	5	90
24	KN-5025	11	charcoal	2967 ± 37	–23.57	1005	5	95
25	KN-5024	11	charcoal	2839 ± 34	–24.19	1010	5	100
26	KN-5236	12	bone ●	2970 ± 30	–20.39	1050	40	140
27	KN-2353	12	charcoal	2990 ± 55	–	1105	55	195
28	KI-1982	12	charcoal	2960 ± 75	–26.1	1110	5	200
29	KN-2354	12	charcoal	3000 ± 50	–	1115	5	205
30	KI-1985	12	charcoal	2990 ± 31	–25.2	1120	5	210

Tab. 4a Kastanás. Radiocarbon Ages. Arranged according to architectural phases (Levels) 6 (young) to 16 (old). Complete data set (2008). Note that ^{14}C-ages nos. 1–13 are not used in the present paper

No.	Lab. Code	Kastanás Level	Material	^{14}C-Age [^{14}C-BP]	δ^{13}C	Expected Age [hist./BC]	Delta [calyrs]	Sum [calyrs]
31	KI-1983	12	charcoal	2990 ± 47	-26.6	1125	5	215
32	KI-1786	12	charcoal	3000 ± 55	–23.9	1130	5	220
33	KI-1984	12	charcoal	3050 ± 43	–26.0	1135	5	225
34	KI-1787	12	charcoal	2950 ± 47	–23.3	1140	5	230
35	KN-2584	12	charcoal	2830 ± 80	–	1145	5	235
36	KN-2585	12–13	charcoal	2770 ± 105	–	1150	5	240
37	KI-1789	13	charcoal	2950 ± 48	–25.7	1155	5	255
38	KN-5238	13	bone ●	2863 ± 26	–20.26	1160	5	250
39	KN-5239	13	bone ●	2892 ± 28	–20.95	1163	3	253
40	KI-1788	13	charcoal	2900 ± 50	–25.8	1165	2	255
41	KN-2355	13	charcoal	3010 ± 55	–	1170	5	260
42	KN-2587	14a–14b	charcoal	3110 ± 50	–	1180	10	270
43	KI-1791	14b	charcoal	3320 ± 50	–25.0	1185	5	275
44	KN-5062	14b	charcoal	2941 ± 34	–25.4	1190	5	280
45	KI-1790	14b	charcoal	3030 ± 50	–25.6	1195	5	285
46	KN-2586	14b	charcoal	3040 ± 50	–	1200	5	290
47	KN-2356	14b	charcoal	3030 ± 120	–	1205	5	295
48	KN-5060	15	charcoal	3114 ± 19	–25.62	1245	40	335
49	KN-5061	15	charcoal	3096 ± 33	–25.42	1255	10	345
50	KN-2357	16	charcoal	3110 ± 55	–	1280	25	370
51	KN-5369	16	bone ●	3119 ± 22	–19.22	1290	10	380
52	KN-5368	16	bone ●	3080 ± 30	–21.30	1300	10	390
53	KN-2358	16	charcoal	3140 ± 50	–	1310	10	400
54	KI-1988	16	charcoal	3280 ± 50	–24.7	1335	25	425
55	KI-1986	16	charcoal	2990 ± 65	–25.3	1340	5	430
56	KI-1987	16	charcoal	3320 ± 65	–24.3	1345	5	435
57	KI-1793	16	charcoal	3110 ± 44	–25.1	1350	5	440
58	KI-1792	16	charcoal	2990 ± 46	–22.5	1355	5	445
59	KN-2359	16	charcoal	3190 ± 50	–	1360	5	450
60	KN-2588	16 or earlier	charcoal	3140 ± 55	–	1365	5	455

Tab. 4b

CalAge (CalBP) Central Ring	CalAge (CalBC) Central Ring	^{14}C-age (BP)	Width (rings)	Lab. Code
3040	1090	2860 ± 16	20	UB-1130
3046	1096	2917 ± 32	10	QL-11108
3046	1096	2965 ± 34	10	QL-11108
3046	1096	2882 ± 22	10	QL-11108
3050	1100	2899 ± 27	10	Hd-10823
3050	1100	2938 ± 24	10	Hd-10822
3055	1105	2891 ± 27	10	UB-1276
3056	1106	2964 ± 25	10	QL-11109
3065	1115	2912 ± 27	10	UB-1275
3066	1116	2909 ± 22	10	QL-11110
3070	1120	2946 ± 21	10	Hd-18586
3075	1125	2945 ± 29	10	UB-1274
3076	1126	3001 ± 21	10	QL-11111
3076	1126	3001 ± 21	10	QL-11111
3080	1130	2955 ± 22	10	Hd-10460
3080	1130	2940 ± 22	20	UB-1128
3080	1130	2962 ± 22	10	Hd-10441
3085	1135	2925 ± 27	10	UB-1273
3086	1136	2914 ± 22	10	QL-11112
3096	1146	2947 ± 23	10	QL-11113
3100	1150	2975 ± 19	20	UB1127
3106	1156	2946 ± 22	10	QL-11114
3116	1166	2949 ± 27	10	QL-11115
3120	1170	2929 ± 22	10	Hd-10440
3120	1170	2942 ± 22	20	UB1126
3126	1176	2901 ± 23	10	QL-11116
3130	1180	2909 ± 29	10	Hd-10439
3136	1186	3027 ± 27	10	QL-11117
3136	1186	2970 ± 33	10	QL-11117
3140	1190	3058 ± 26	10	Hd-21712
3140	1190	2956 ± 22	20	UB1125
3146	1196	2918 ± 23	10	QL-11118
3156	1206	3005 ± 21	10	QL-11119
3156	1206	3040 ± 21	10	QL-11119
3156	1206	2924 ± 22	10	QL-11119
3160	1210	3002 ± 19	20	UB1124
3166	1216	3002 ± 22	10	QL-11120
3176	1226	2965 ± 23	10	QL-11121
3180	1230	2930 ± 19	20	UB1123
3186	1236	2990 ± 23	10	QL-11122
3196	1246	2985 ± 18	10	QL-11123

Tab. 5 Tree-Ring ^{14}C-age INTCAL04 calibration raw data (Laboratories QL and UB) and complementary high-precision ^{14}C-ages for tree-ring dated wood sample from Anatolia (Laboratory Hd) in the time-window 1250–1100 calBC. Sources of numeric data: www.radiocarbon.org/IntCal04.htm, Dataset 1 – University of Washington (QL), Dataset 2 – Queen's University Belfast (UB); Floating Anatolian tree-ring data according to Kromer *et al.* 2001 and Manning *et al.* 2001, as augmented with further data by Manning *et al.* 2003. Source of numeric data: www.arts.cornell.edu/dendro/antiquity.html

CalAge (calBP) Center Ring	CalAge (CalBC) Center Ring	^{14}C-Age (BP)	Width (rings)	Lab. Code
3216	1266	3032 ± 22	10	QL-11125
3220	1270	3025 ± 23	20	UB1121
3226	1276	2994 ± 23	10	QL-11126
3236	1286	3035 ± 22	10	QL-11127
3240	1290	3042 ± 23	20	UB1120
3246	1296	3026 ± 24	10	QL-11128
3250	1300	3060 ± 21	10	Hd-21761
3256	1306	3040 ± 23	10	QL-11129
3260	1310	3096 ± 22	20	UB1119
3266	1316	3079 ± 33	10	QL-11130
3266	1316	3079 ± 33	10	QL-11130
3266	1316	3154 ± 35	10	QL-11130
3270	1320	3144 ± 20	10	Hd-21722
3276	1326	3058 ± 22	10	QL-11131
3280	1330	3122 ± 20	10	Hd-21721
3280	1330	3039 ± 22	20	UB1118
3286	1336	3043 ± 23	10	QL-11132
3290	1340	3106 ± 20	10	Hd-21774
3296	1346	3071 ± 22	10	QL-11133
3300	1350	3030 ± 25	20	UB1117
3306	1356	3030 ± 21	10	QL-11134
3316	1366	3087 ± 21	10	QL-11135
3320	1370	3053 ± 21	20	UB1116
3326	1376	3091 ± 21	10	QL-11136
3330	1380	3062 ± 25	10	Hd-21711
3331	1381	3223 ± 21	10	Hd-19973
3336	1386	3117 ± 16	10	QL-11137
3340	1390	3097 ± 19	20	UB1115
3346	1396	3099 ± 21	10	QL-11138
3356	1406	3168 ± 21	10	QL-11139
3360	1410	3180 ± 22	20	UB1114
3366	1416	3118 ± 22	10	QL-11140
3376	1426	3204 ± 21	10	QL-11141
3376	1426	3147 ± 23	10	QL-11141

Tab. 6 Tree-Ring ^{14}C-age INTCAL04 calibration raw data (Laboratories QL and UB) and complementary high-precision ^{14}C-ages for tree-ring dated wood sample from Anatolia (Laboratory Hd) in the time-window 1420–1280 calBC. Sources of numeric data: www.radiocarbon.org/IntCal04.htm, Dataset 1 - University of Washington (QL), Dataset 2 – Queen's University Belfast (UB); Floating Anatolian tree-ring data according to KROMER *ET AL.* 2001 and MANNING *ET AL.* 2001, as augmented with further data by MANNING *ET AL.* 2003. Source of numeric data: www.arts.cornell.edu/dendro/antiquity.html

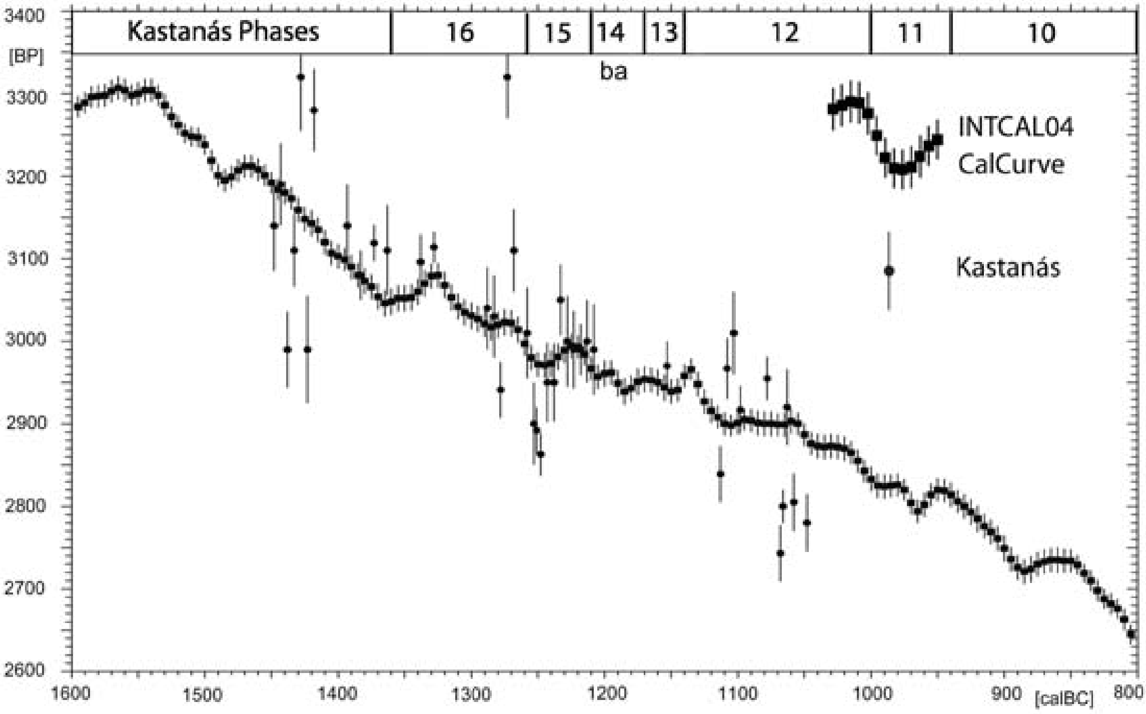


Fig. 1 Stratigraphically sequenced radiocarbon ages from Kastanás (black dots), fitted to the INTCAL04 ^{14}C-age calibration curve (black squares) by Monte Carlo Wiggle Matching. The stratigraphically sequenced ^{14}C-ages (Tab. 4) give a best-fit age, referenced to the youngest sample (KN-5233: Tab. 4) of 1045 ± 20 calBC (N=10.000 Iterations Input: σ_{phase}= ± 20 yrs, $\sigma_{calcurve}$= ± 10 yrs). According to the applied method, all other (N=41) ^{14}C-ages then automatically fall into their respective calendric age positions. Dates in Tab. 4 with standard deviations larger than 65 BP have been excluded from the analysis

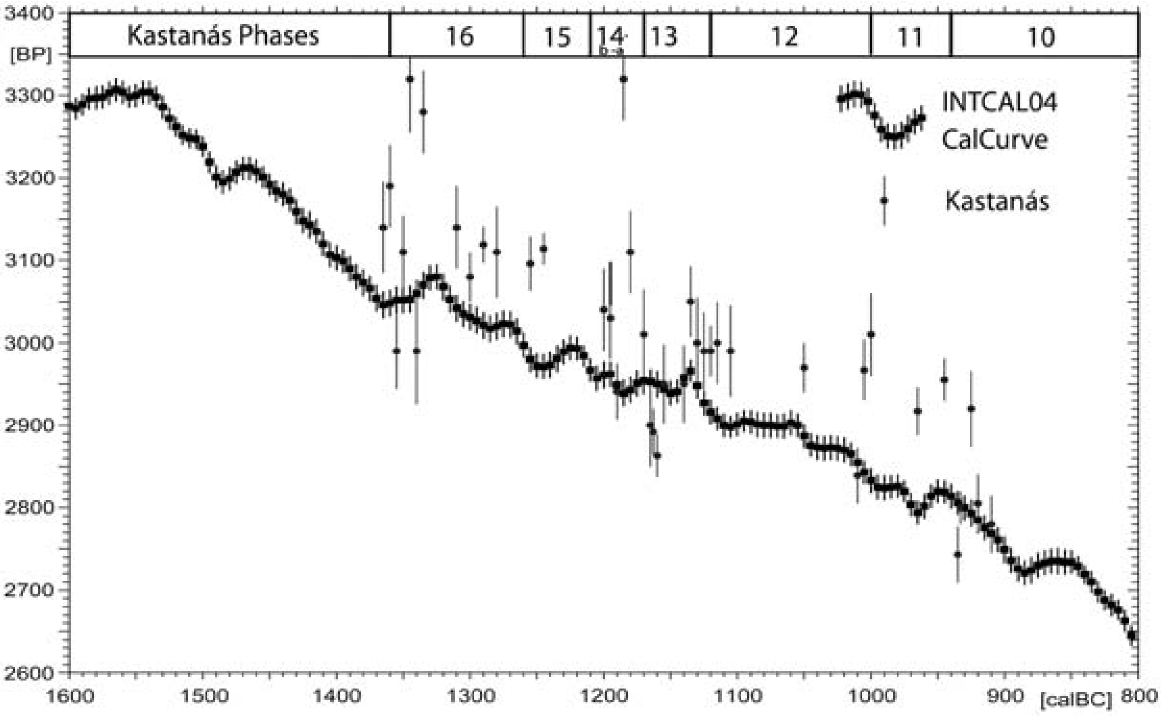


Fig. 2 Historically sequenced radiocarbon ages from Kastanás (black dots), in comparison with the INTCAL04 ^{14}C-age calibration curve (black squares). In construction of this graph, no direct use was made of the tree-ring calibration curve. The tree-ring ^{14}C-data (black squares at 5 yr intervals) are only included in this graph for visual comparison

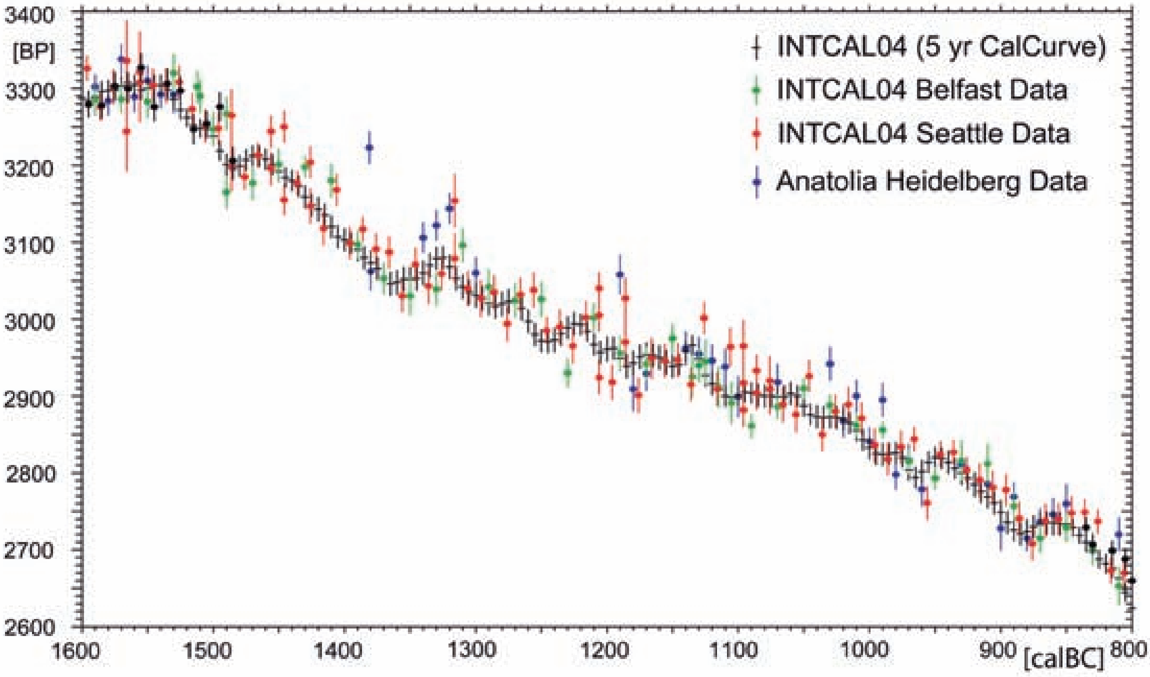


Fig. 3 Tree-Ring Calibration INTCAL04 Curve (1600–800 calBC), showing the construction raw data (Belfast and Seattle) and additional high- precision measurements (Heidelberg) in comparison to the internationally recommended calibration curve (sequence of data bars at 5 calyr intervals). The strong wiggles at ~1330 calBC and ~ 1100 calBC are not included in the calibration curve

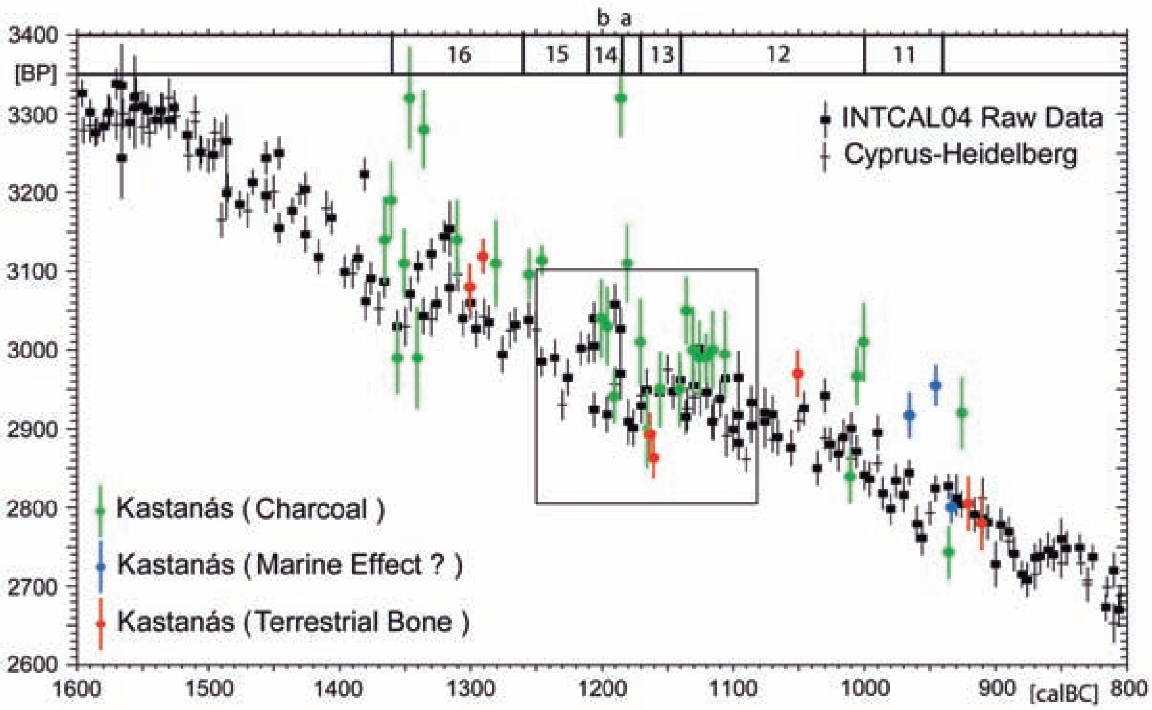


Fig. 4 Tree-Ring Calibration INTCAL04 rawdata (sequence of data bars at 5 calyr intervals, 1600–800 calBC) in comparison to Kastanás historical ^{14}C-age model. Excluding a few outliers, the historical ^{14}C-sequence is seen to follow the INTCAL04 rawdata, but not the INTCAL04 curve (cf. Fig. 3)

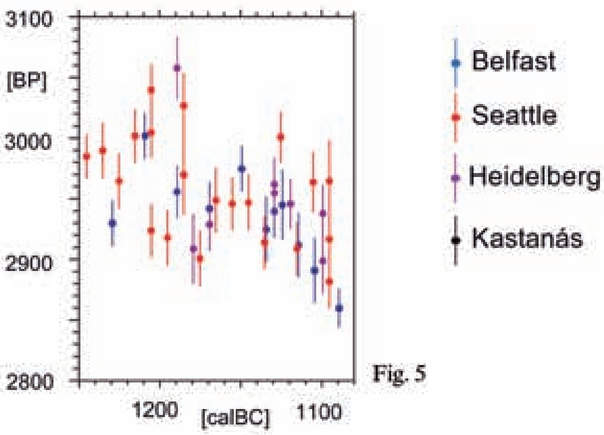


Fig. 5

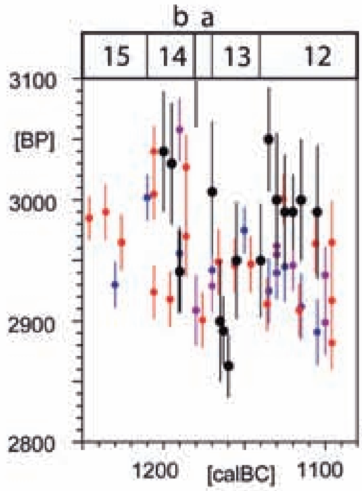


Fig. 6

Fig. 5 Tree-Ring Calibration INTCAL04 rawdata (1250–1080 calBC) of Belfast (blue bars) and Seattle (red bars) and additional high-precision measurements by Heidelberg (violet bars). Calendric scale width of decadel and bidecadel tree-ring blocks not shown. For the interval 1230–1180 calBC, due to wide spread of raw-data, it is impossible to construct a smooth calibration curve as shown in Fig. 3. Note the possible strong jump of data down from 1200 calBC (~3050 BP) to 1170 calBC (~2900 BP). Numeric values: Tab. 5

Fig. 6 Tree-Ring Calibration INTCAL04 rawdata (1250–1080 calBC) as shown in Fig. 5 in addition Kastanás archaeological data according to historical ^{14}C-age model. The strong jump of calibration rawdata down from 1200 calBC (~3050 BP) to 1170 calBC (~2900 BP) also appears in the archaeological data. Note the positioning of 3 Kastanás Level 13 dates (2 bones, 1 charcoal) shortly below the "wiggle" at 1180 calBC and following jump of Kastanás Level 12 dates up to values ~ 3000 BP, corresponding to calibration raw-data. Numeric values: Tab. 5 and Tab. 4

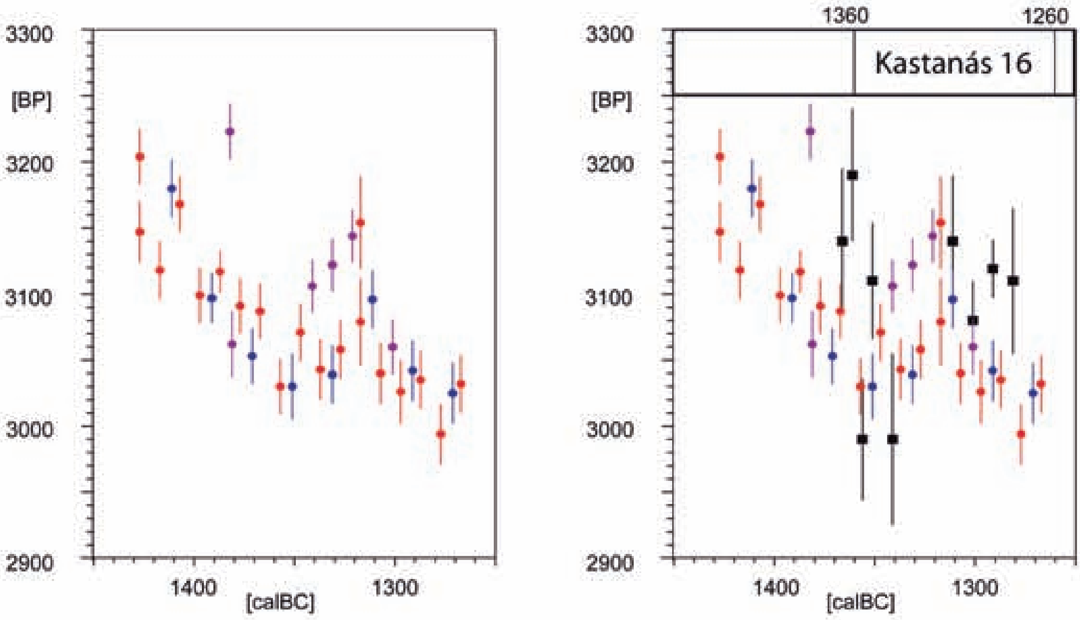
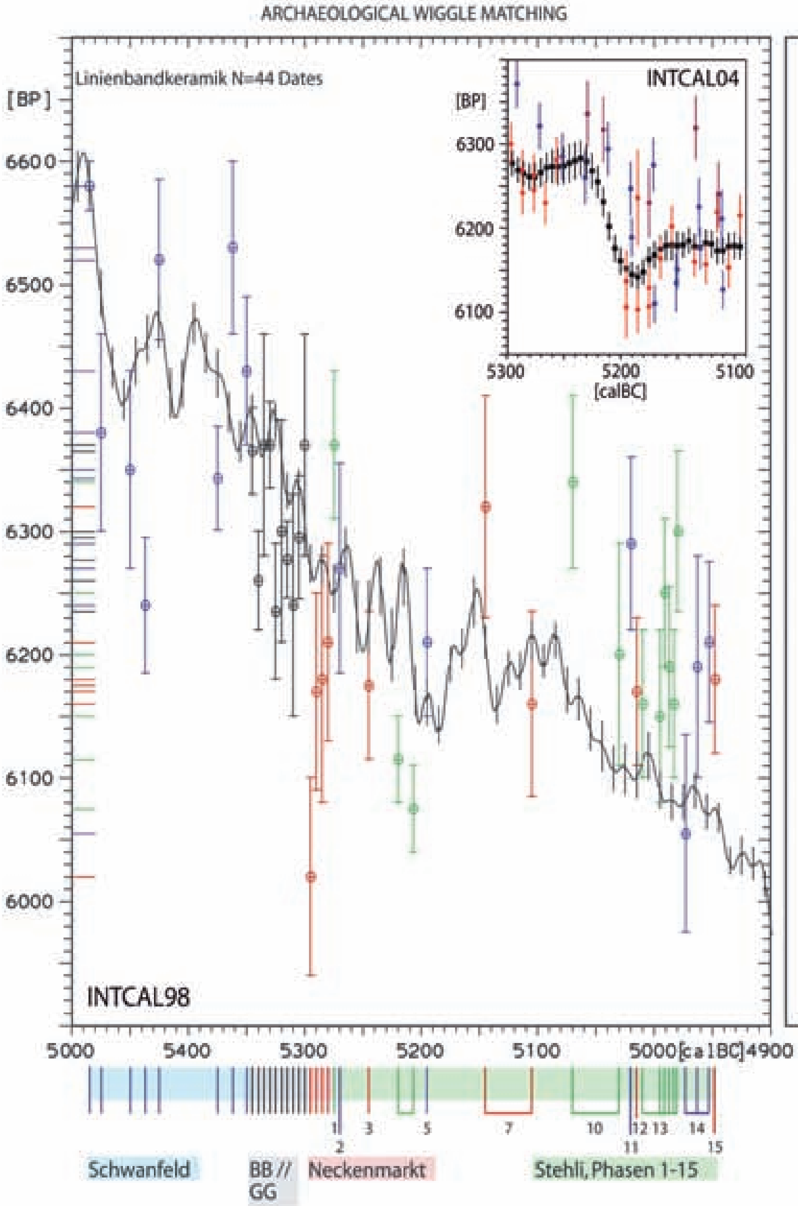


Fig. 7 (Left): Tree-Ring Calibration INTCAL04 rawdata (1450–1260 calBC) of Belfast and Seattle, with additional high-precision measurements by Heidelberg (Tab. 6)

Fig. 7 (Right): Calibration rawdata as shown in Fig. 7 (left), in addition archaeological ^{14}C-data according to Kastanás historical age-model (Tab. 4). Note the strong jump (up) in Kastanás (phase 16) ^{14}C-ages from ~ 1350 calBC (~3000 BP) to ~ 1310 calBC (~3150 BP), in agreement with calibration rawdata which show a wiggle at ~ 1330 calBC. In the recommended calibration INTCAL04, this wiggle is lost due to over-smoothing (Fig. 3). Numeric values: Tab. 6 and Tab. 4



DATE LIST

Nr	Lab Number	Date [14C-BP]	Date [calBC/AD]	Delta [a]	Sum [a]
1	Phase XV	6180 ± 60	4948	0	0
2	Phase XIV	6210 ± 65	4953	5	5
3		6190 ± 90	4963	10	15
4		6055 ± 80	4973	10	25
5	Phase XIII	6300 ± 65	4980	7	32
6	OxA-2896	6160 ± 60	4983	3	35
7		6190 ± 65	4987	4	39
8	OxA-2901	6250 ± 60	4991	4	43
9		6150 ± 70	4995	4	47
10	OxA-2900	6160 ± 60	5010	15	62
11	Phase XIIOxA	6170 ± 60	5015	5	67
12	Phase XI OxA	6290 ± 70	5020	5	72
13	Phase X	6200 ± 90	5030	10	82
14		6340 ± 70	5070	40	122
15	Phase VII	6160 ± 75	5105	35	157
16		6320 ± 90	5145	40	197
17	Phase V	6210 ± 60	5195	50	247
18	Vera-1417	6075 ± 35	5207	12	259
19	Vera-1416	6115 ± 35	5220	13	272
20	Phase III	6175 ± 60	5245	25	297
21	Phase II	6270 ± 85	5270	25	322
22	Phase I	6370 ± 60	5275	5	327
23	N-OxA-1536	6210 ± 80	5280	5	332
24	N-OxA-1535	6180 ± 100	5285	5	337
25	N-OxA-1534	6170 ± 80	5290	5	342
26	N-OxA-1533	6020 ± 80	5295	5	347
27	BB-KI-2598	6370 ± 90	5300	5	352
28	G-Hd-14173	6295 ± 50	5305	5	357
29	BB-oxa-1629	6240 ± 90	5310	5	362
30	G-Hd+OxA	6277 ± 31	5315	5	367
31	G-OxA-1628	6300 ± 90	5320	5	372
32	BB-Hd-14273	6235 ± 55	5325	5	377
33	G-Hd-14176	6370 ± 35	5330	5	382
34	BB-2599	6370 ± 90	5335	5	387
35	G-Hd-14009	6260 ± 40	5340	5	392
36	BB-hd-14548	6365 ± 35	5345	5	397
37	S- KN-3427	6430 ± 60	5350	5	402
38	S- KN-3436	6530 ± 70	5362	12	414
39	S- Hd-14111	6343 ± 42	5375	13	427
40	S- KN-3425	6520 ± 65	5425	50	477
41	S- Hd-14032	6240 ± 55	5437	12	489
42	S- UtC-2340	6350 ± 80	5450	13	502
43	S- OxA-1539	6380 ± 80	5475	25	527
44	S- Hd-14219	6580 ± 20	5485	10	537

Fig. 8 Radiocarbon Chronology of the Central European Early Neolithic Linear Pottery Culture based on N=44 archaeological ^{14}C-ages (Date List: right), sequenced according to LÜNING (2005) in comparison to INTCAL98 curve (STUIVER *ET AL.* 1998b). The graphic inlay (main picture, upper right) shows INTCAL04 curve (square data bars: REIMER *ET AL.* 2004) and INTCAL04 raw data (dotted data bars) of laboratories Seattle, Belfast and Heidelberg. Due to selective dating of 'old wood' (archaeological charcoal), the majority of ^{14}C-ages on samples for Stehli LBK-Phases 1–15 (5200–4950 calBC) are found to be arranged systematically at positions 'above' the INTCAL98 calibration curve (thin line connecting 68%-error bars). Note the positions under the INTCAL98-curve of two AMS ^{14}C-ages measured by VERA-laboratory on human bone (VERA-1417: 6075 ± 35 BP; VERA-1516: 6115 ± 35 BP) from the cemetery of Flomborn. As shown in the inlay, for this interval (5200–5160 calBC), there are two groups of calibration raw-data. The first has ^{14}C-values ~ 6100 BP; the second has values ~ 6200–6280 BP. Due to lack of data, in combination with over-smoothing construction methods, both calibration curves INTCAL98 and INTCAL04 are not well adapted, in this time-window, to wiggle-matching studies

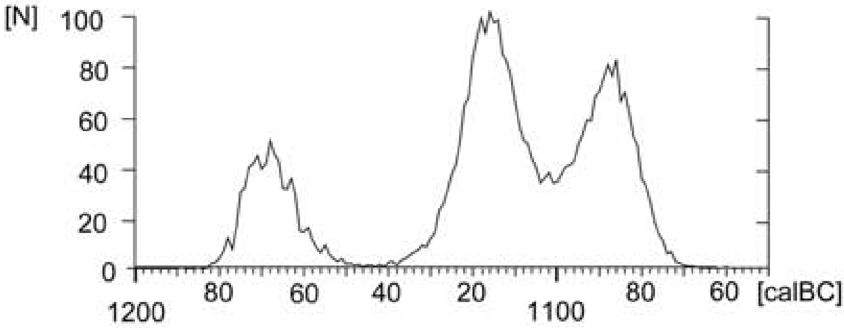


Fig. 9 Ássiros. Results of Gaussian Monte Carlo Wiggle Matching for wooden posts from Phases 3 and 2 (cf. text). Data: NEWTON – WARDLE – KUNIHOLM (2005, 183 fig. 8)

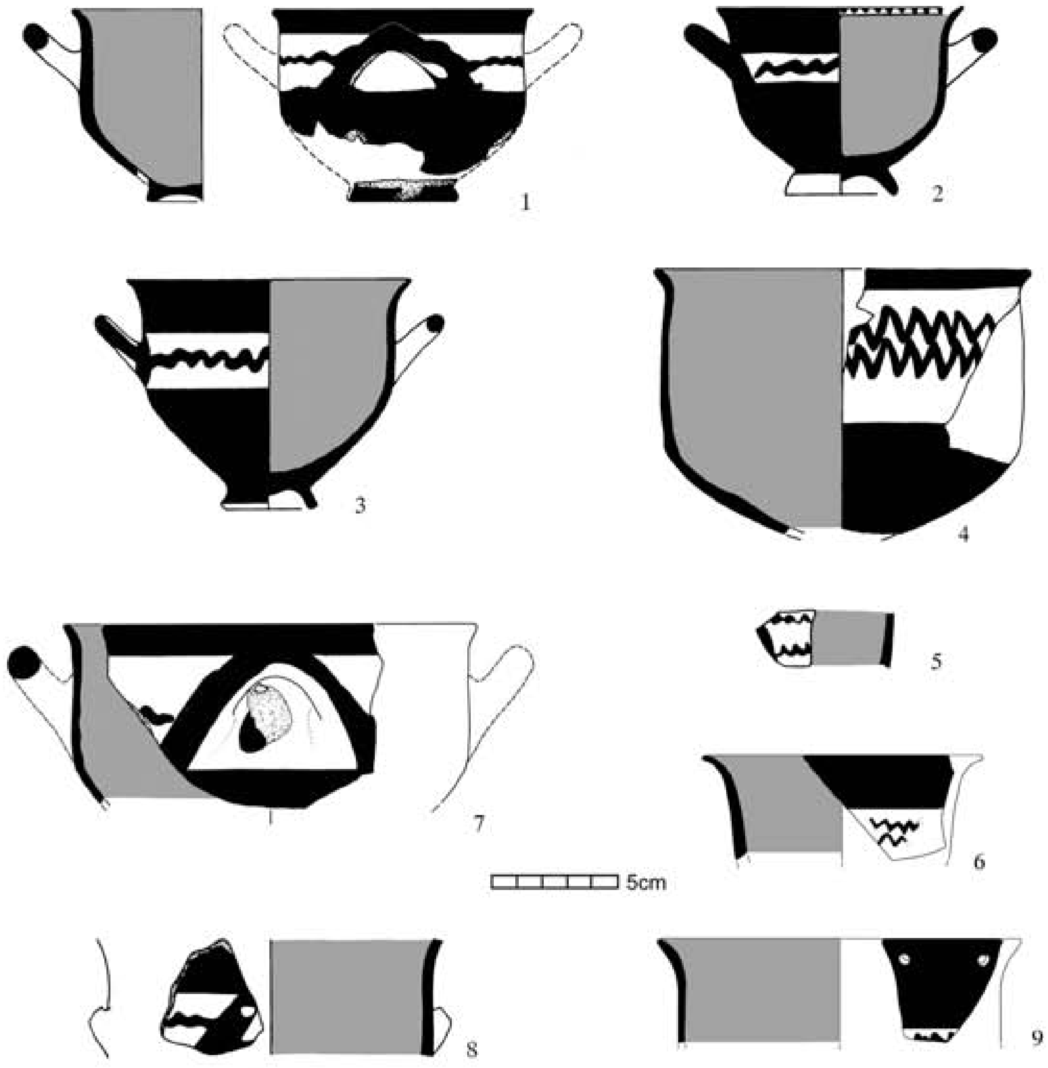


Fig. 10 Submycenaean deep bowls with monochrome decoration and reserved outer zone carrying a single or double horizontal zigzag from Greece and Italy. 1, 4, and 7 from Kastanás, Level 12 (after JUNG 2002, pl. 24:272.274 and pl. 23:259); 2 from Lefkandí, Skoubris Tomb 55 (after POPHAM – SACKETT – THEMELIS 1979/80, pl. 107:55.2); 3 from Kerameikos tomb S1 (after MOUNTJOY 1988, 16 fig. 13:Gr.1); 5 and 8 from Tiryns, Lower Citadel, Submycenaean Horizon (after PAPADIMITRIOU 1988, 229 fig. 1:22.28); 6 and 9 from Rocavecchia, FBA 2 (after JUNG 2006, pl. 12:2.3). Scale : all 1:3

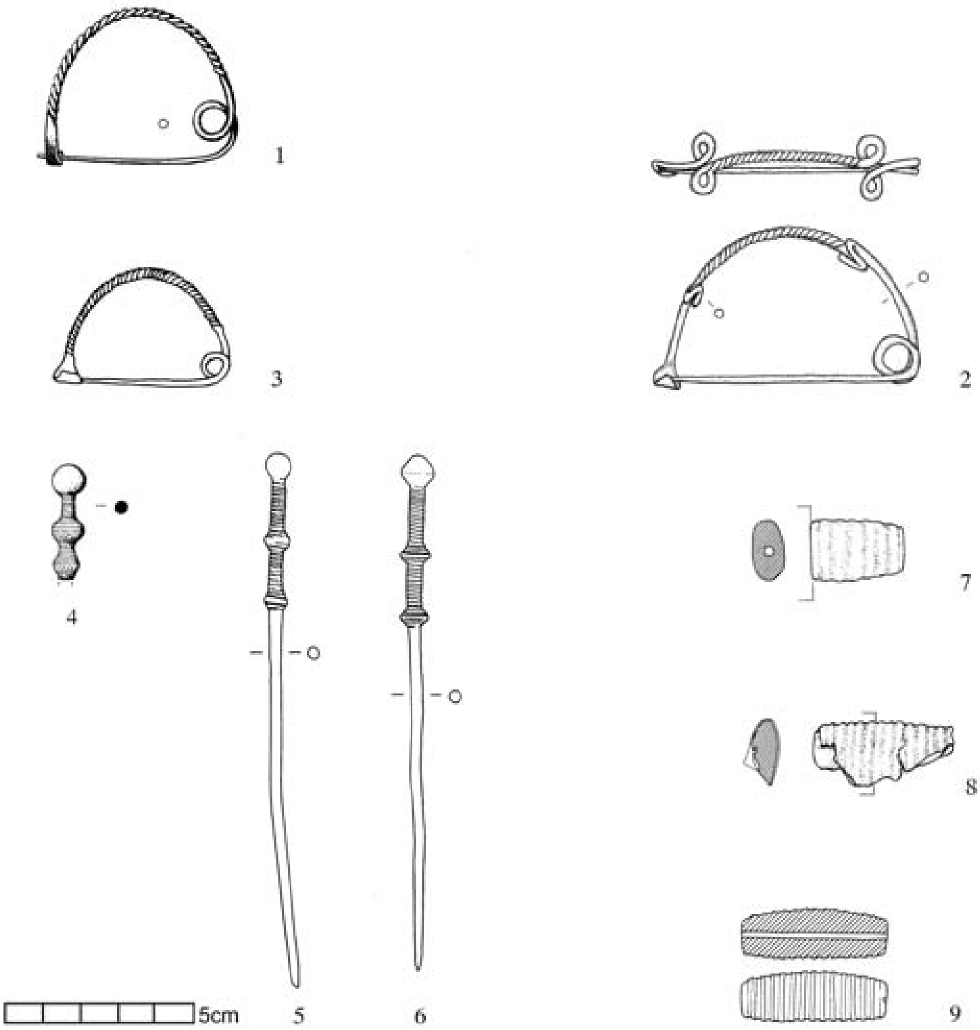


Fig. 11 1–3 twisted bow fibulae from Greece and Italy. 1 from Kerameikos tomb S 108 (after MÜLLER-KARPE 1962, 87 fig. 5:10); 2 from Rocavecchia hoard 2 (after MAGGIULLI in press, fig.); 3 from Frattesina hoard I (after JUNG 2006, pl. 14:2). – 4–6 incised pins with globular head and two globules below from northern Italy and Switzerland. 4 from Narde, tomb 227 (after SALZANI 1989, 38 fig. 16:10); 5 and 6 from Hauterive-Champréveyres, Level 3 (after RYCHNER-FARRAGI 1993, pl. 55:4.5). – 7–9 amber beads of Allumiere type from central Italy and Swizzerland. 7 and 8 from Capo del Fico (after DELPINO 1987, 32 fig. 18:7–12); 9 from Hauterive-Champréveyres, Level 3 (after RYCHNER-FARRAGI 1993, pl. 124:6). Scale: all 1:2

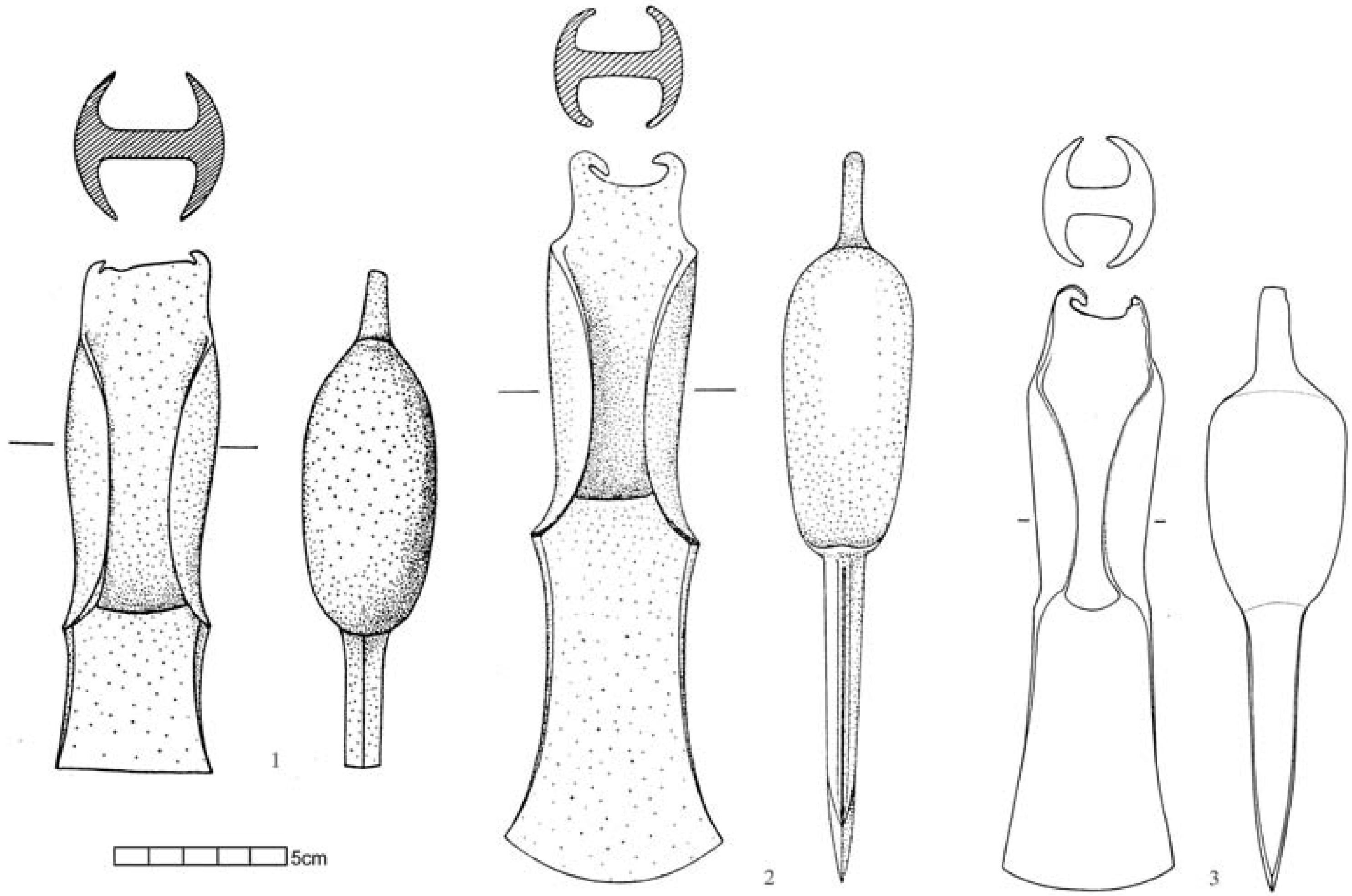


Fig. 12a 1–3 winged axes with wings placed close to the neck. 1 and 2 from Monte Primo, hoard (after Peroni 1963, I.7.8-[3] no. 9; 8-[8] no. 42); 3 from Hauterive-Champréveyres, Level 3 (after Rychner-Faraggi 1993, pl. 24:2). Scale: all 1:2

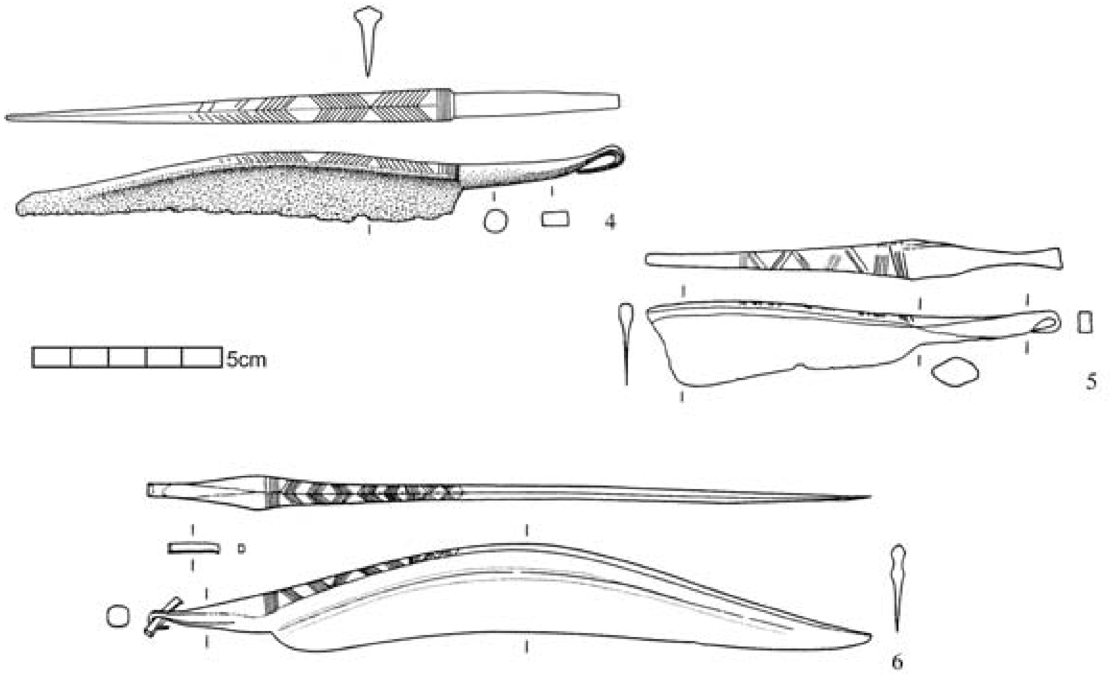


Fig. 12b 4–6 Tanged knives with bulging back and a loop at the tang end. 4 from Poggio Berni, hoard (after BIANCO PERONI 1976, pl. 31:257); 5 and 6 from Hauterive-Champréveyres, Level 3 (after RYCHNER-FARRAGI 1993, 66 pl. 30:8.9). Scale: all 1:2

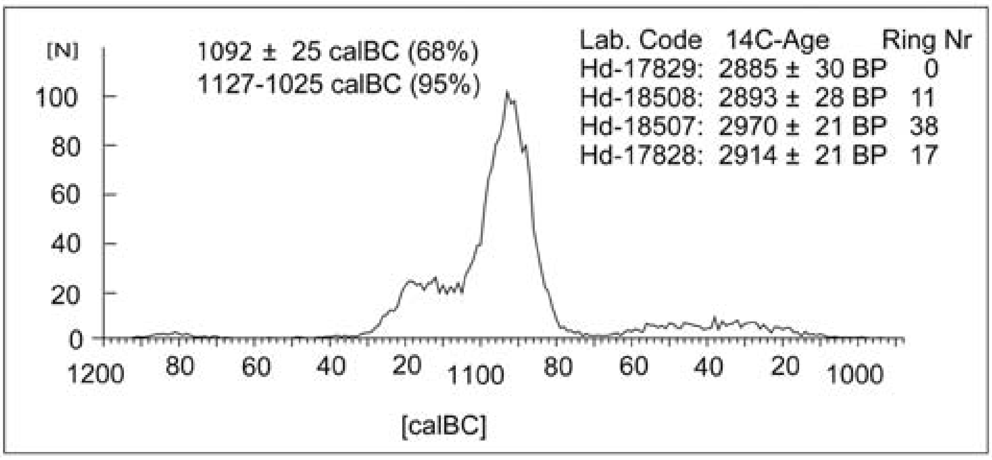


Fig. 13 Application of Gaussian Wiggle Matching to the floating Livorno ^{14}C-age sequence (data: ZANINI-NARTINELLI 2005)

<table>
<tr><th>Phases / Architectural horizons at Tiryns, Lower Citadel (Podzuweit 2007)</th><th>Tell Kazel, Ugarit (historic-archaeological, Jung 2008)</th><th>Italy, Switzerland (dendro and ^{14}C)</th><th>Kastanás (^{14}C)</th><th>Proposal (BCE)</th></tr>
<tr><td>1 Hor. III B Final (palace destruction)</td><td rowspan="13">c. 1197/75 destruction at the beginning of III C Early</td><td rowspan="10">– 1070/40
FBA 2/ Submycenaean</td><td>Level 15 (III B Developed and Final)</td><td>– 1210/00</td></tr>
<tr><td>1st Hor. III C Early</td><td>Levels 14b and 14a</td><td rowspan="2">1210/00 –
LH III C Early
– 1170/60</td></tr>
<tr><td>2nd Hor. III C Early</td><td rowspan="4">1180/70 start Level 13 (still in III C Early?)</td></tr>
<tr><td>1st Hor. III C Developed</td><td rowspan="2">1170/60 –
LH III C Developed
– 1150/40</td></tr>
<tr><td>2nd Hor. III C Developed</td></tr>
<tr><td>1st Hor. III C Advanced</td><td rowspan="3">1150/40 –
LH III C Advanced
– 1100</td></tr>
<tr><td>2nd Hor. III C Advanced</td><td rowspan="5">1130/20 start Level 12 (in III C Advanced)</td></tr>
<tr><td>3rd Hor. III C Advanced</td></tr>
<tr><td>1 Hor. III C Late</td><td>1100 – 1085/80
LH III C Late</td></tr>
<tr><td rowspan="4">1 Hor. Submycenaean</td><td>1085/80 – 1070/40
Submycenaen</td></tr>
<tr><td rowspan="3"></td><td>1070/40 – 1000
EPG</td></tr>
<tr><td>c. 1000 start Layer 11 (MPG)</td><td></td></tr>
<tr><td>middle of 10th cent. during Layer 10 (LPG)</td><td></td></tr>
</table>

Fig. 14 Proposal for the absolute chronology of the end of the Aegean Bronze and the beginning of the Early Iron Age