STRATIFIED ^{14}C DATES AND CERAMIC CHRONOLOGIES: CASE STUDIES FOR THE EARLY BRONZE AGE AT TROY (TURKEY) AND EZERO (BULGARIA)

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ABSTRACT. Prehistoric tell stratigraphies, like deep-sea sediments or peat deposits, store information about past atmospheric ^{14}C variations. By matching the ^{14}C ages on charcoal samples from settlement deposits with the tree-ring calibration curve, estimates for the time span covered by successive stratigraphic phases can be derived. This method is applied to ^{14}C data from the tell mounds at Troy, Turkey and Ezero, Bulgaria. I compare the derived chronologies with the results of pottery shape seriation using correspondence analysis.

INTRODUCTION

A continuing problem in archaeology is analyzing and interpreting the increasingly large ^{14}C data sets. A first solution to this problem was to use the histogram method (Geyh 1969), enabling large sets of grouped data to be analyzed graphically. Over the years, a variety of statistical and archaeological procedures appropriate to histogram analysis of archaeological ^{14}C data have been developed (Jaguttis-Emden 1977; Pape 1979; Geyh 1980; Geyh and Maret 1982; Breunig 1987). In continuing this line of research, a method to calibrate ^{14}C histograms was developed, allowing the data to be presented on a time scale more convenient to archaeologists (Weninger 1986; Robinson 1986). Parallel to these methods, further proposals have been made for graphic display of calibrated ^{14}C data (Ottaway 1973; Pazdur and Michczynska 1989; Aitchison, Ottaway and Al Ruzaiza 1991; van der Plicht 1993).

The present state of affairs is that a variety of calibration methods exist, many of which now make use of the additional information on sample stratigraphy as supplied by archaeologists (Buck, Litton and Smith 1992; Buck, Litton and Scott 1994). The problem remains that ^{14}C histograms, and the derived calibrated distributions, are distorted by "wiggles" (Suess 1970) in the tree-ring calibration curve. The unrealistic width of calibrated probability distributions, and the mathematical difficulties encountered in correction procedures (Stolk, Hogervorst and Berendsen 1989; Weninger 1990, 1992a; Dehling and van der Plicht 1993), encourage wiggle-matching techniques, which promise more accurate results for sequenced archaeological data (Weninger 1986, 1987, 1992b; Manning 1995; Manning and Weninger 1992).

Wiggle Matching

First applied by Ferguson, Huber and Suess (1966), "wiggle matching" represents one of the most powerful statistical tools available for analysis of sequenced ^{14}C data. Perhaps its most important application is the precise calendrical dating of known-growth-period samples with limited time spans, *e.g.*, trees with 40 to 200 rings, supporting construction of tree-ring chronologies. Combining large sets of tree-ring and ^{14}C data, wiggle matching can also be used to accurately measure laboratory modern standards (Stuiver and Pearson 1986; Pearson and Stuiver 1986). Pearson (1986) described wiggle matching in mathematical detail.

In this paper, I apply wiggle matching to ^{14}C data on samples from archaeological deposits. In contrast to tree-ring samples with well-defined growth periods, the problem here is to derive age estimates for deposits known (or judged) to have non-linear accumulation rates, including the possibility of time gaps. Examples are the time span represented by consecutive building phases in a tell settlement, the

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time sequence of burials in a prehistoric cemetery or a sequence of cultural subphases derived from ceramic analysis. These examples share a duration in the range of 100 to 300 yr, similar to the range of the century-type Suess wiggles. Archaeological profiles often show quasi-annual deposits (*e.g.*, clay floors), or even daily lamination (*e.g.*, rain-washed fill of a fortification trench). However, in such cases, the range of 1 to 10 yr seems too short for wiggle matching.

In comparable applications, where the sample growth function is initially unknown but can be assumed (or demonstrated) to be linear (*e.g.*, peat layers), wiggle matching has also been adapted to derive estimates for the calibrated time intervals represented in a profile (van Geel and Mook 1989). The method varies (expands and compresses) the length of the sample sequence, until a "best" fit of the data and the calibration curve is achieved. In the case of peat deposits, knowledge of the linearity of annual growth can be used to smooth the calibration curve according to the number of years in the samples (Mook 1983).

The time resolution achieved by wiggle matching, as applied to different types of ^{14}C data, depends on a variety of parameters, of which the most important are the number of dates available, their standard deviations, the time span covered by the samples, the shape of the calibration curve and the linearity of the deposit. In general, the advantage of wiggle matching is to enhance the dating accuracy for all samples in a series, using the available archaeological, botanical or geophysical information.

Wiggle matching in archaeology can be very difficult, especially when the ^{14}C ages of a sample series cover several wiggles of the tree-ring calibration curve. When the calibration curve is more-or-less flat, the ^{14}C method is essentially "blind" to time differences of 50–300 yr. This is the starting point for combining wiggle matching with refined, archaeological methods of stratigraphic analysis.

Tell Stratigraphies

Prehistoric tell mounds of the Neolithic, Bronze and Iron Ages are abundant in southeastern Europe, Anatolia and the Near East. A typical tell mound, at least 5 m deep, contains the remains of large numbers of superimposed houses, fortification walls, gates, storage pits and other secondary structures. Typical building materials are stone, mudbrick and wood. The samples submitted to laboratories are mainly charred wood, carbonized cereals and, less frequently, animal bone.

In a tell settlement, it is natural for deposits to show secondary disturbances. Consider the construction of a typical fortification system. It consists of a massive stone wall topped by a heavy mud-brick superstructure. To support the weight of such a structure, a deep (1–2 m) foundation wall is necessary. When digging the foundation trench, workers bring up large amounts of old material and spread this material over the working surface. Having set the stone foundation, the workers backfill the trench, again displacing large amounts of material.

When the upper walls eventually decay, the building materials and associated artifacts are redeposited. The result of such processes can be thorough displacement and mixing of the archaeological objects, even for minor structures (*e.g.*, storage pits). Thus, although seemingly "well-stratified", many tell deposits contain objects of different ages. This complicates the application of archaeological dating methods, notably when applied to the pottery finds most often used in chronological studies. Unfortunately, little is yet known about the sedimentary processes underlying the corresponding ^{14}C samples.

For typical disturbed deposits, the advantage of combining larger ^{14}C data sets with statistical ceramic dating methods appears to be twofold. First, when ceramic comparisons are based on large quantities of sherds, checking the ceramic dates against the stratigraphy is possible. Second, statistical ceramic dating methods allow for the estimation of uncertainty limits. Thus, the ceramic data can be used not only for chronological purposes, but also to study the complex sedimentological and historic processes affecting archaeological deposits (Easton and Weninger 1993).

Ceramic Seriation

I analyze here two series of ^{14}C ages on charcoal from the Early Bronze (EB) Age sites of Ezero (Bulgaria) and Troy (northwest Anatolia), first, in relation to the building phases, and second, in comparison with the results of pottery shape seriation using correspondence analysis (CA) (Benzecri 1980a,b; Bolviken *et al.* 1982; Ihm and Groenewould 1984). The basic assumption underlying archaeological seriation methods such as CA is that, in the course of time, new artifacts will gradually replace the older types. If the artifacts, having been discarded, are deposited quickly (*e.g.*, in pits, floor levels, destruction layers or burials), then the deposits will contain artifacts in use at the same time. Accordingly, the percentage variations of the different ceramic types found in the deposits can be used for dating purposes. With real archaeological data, we must, of course, remain aware of possible deviations from this model.

In reconstructing an unknown ceramic sequence using CA, the first step is to arrange the data in a contingency table $A = (a_{nm})$ with n rows (archaeological deposits) and m columns (pottery types). Each entry a_{ij} represents the number of finds of type j associated with deposit i. The table is then rearranged so that the correlation (or "correspondence") between the rows and columns reaches a maximum. The output is a list of coordinates for the deposits and pottery types scaled to the same low-dimensional hyperspace. The coordinates, in combination with the original data, can be used to plot a "battleship" diagram of the seriation results (Easton and Weninger 1993).

Results

Ezero

The tell mound at Ezero contains 13 consecutive building phases ("Bauhorizonte") of the EB Age. The buildings are wood-mudbrick constructions. Typological analysis of the ceramic finds (fabrics, pot shapes, handles) indicates an uninterrupted cultural development through phases 13 (old) to 2 (young). The pottery from the younger phases is similar, mainly in handle shapes, to the ceramics from Troy I (Georgiev *et al.* 1979). The Berlin laboratory measured 27 ^{14}C dates on carbonized wood and grain samples from all phases 13–4, with the exception of phases 12 and 5 (Table 1).

Figure 1 shows the calibrated ^{14}C distribution of the data. The distribution has three peaks, corresponding to the changing shape of the calibration curve between 3400 and 2500 cal BC. A danger exists that the shape of the cal date distribution is erroneously interpreted as representing three consecutive archaeological subperiods, each lasting *ca.* 300 cal yr. The overall time span of *ca.* 900 yr does not agree with the length of time we can reasonably assume for the stratigraphy on archaeological grounds. For simple mudbrick houses of the type found at Ezero, we can hardly expect a lifetime of >50 yr, long before which the houses would deteriorate by rain-washing. The 13 consecutive building phases at Ezero should, by this reasoning, represent, at the most, 650 yr. On the other hand, a lifetime <10 yr also seems unlikely, due to the work invested and housing necessities. The total time span covered by building phases 13–1 can rather be expected to lie between 130 and 650 yr, assuming these limits of minimum 10 yr and maximum 50 yr per phase.

To help identify the actual time span of the settlement, the wiggle-matching technique was applied to the ^{14}C data. For each phase length, 10–50 yr, the "best" preliminary fit of the ^{14}C sequence to the

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TABLE 1. Ezero ^{14}C Dates Arranged in Stratigraphic Order. After Quitta and Kohl (1969) and Bojadziev (1992)

Lab no (Bln-)	^{14}C age (BP ± 1 σ)	Building phase	Phase average (BP ± 1 σ)	Material
429	4130 ± 100	4		Grain
428	4260 ± 80	4		Grain
427	4365 ± 80	4	4268 ± 49	Charcoal
421	4335 ± 80	6		Grain
422	4310 ± 80	6	4323 ± 57	Charcoal
423	4440 ± 80	7		Charcoal
424	4575 ± 80	7		Charcoal
522	4455 ± 100	7		Charcoal
526	4135 ± 100	7		Charcoal
523	4410 ± 100	7		Charcoal
524	4460 ± 100	7		Grain
525	4280 ± 100	7	4409 ± 35	Charcoal
527	4390 ± 80	8		Grain
528	4445 ± 100	8		Charcoal
529	4375 ± 100	8	4401 ± 53	Charcoal
724	4365 ± 150	9		Grain
722	4285 ± 100	9		Grain
1103	4280 ± 100	9	4298 ± 64	Charcoal
725	4120 ± 100	10		Grain
726	4285 ± 100	10		Grain
727	4215 ± 100	10	4207 ± 58	Grain
902	4360 ± 100	11	4360 ± 100	Charcoal
1786	4450 ± 80	13		Charcoal
1843	4430 ± 50	13		Charcoal
1841	4420 ± 50	13		Charcoal
1837	4415 ± 40	13		Charcoal
1838	4305 ± 60	13	4460 ± 23	Charcoal

calibration curve was derived, in steps of 5 yr, using the root-mean square (rms) deviations of the ^{14}C ages and the calibration data. Figure 2 shows the results for an average phase length of 25 cal yr, which was judged to be the overall "best" result, by archaeological reasoning.

These results are based on combined phase averages of the ^{14}C data. I acknowledge that the data set, which includes potentially long- and short-lived samples, does not strictly match the criteria of Ward and Wilson (1978). Using the combined phase averages, however, the wiggle-matching results are easier to evaluate graphically. The same results are achieved by wiggle matching the raw data. Although the results appear satisfactory, there may exist additional sources of error not yet covered in the analysis. Probably the most important caveat against the 25-yr/phase hypothesis is that, because the calibration curve is essentially flat between 3200 and 3000 cal BC, breaks in the stratigraphic sequence of 30–100 yr would remain undetected by the ^{14}C dates. A related problem is that little information can be derived from the ^{14}C data about re-used wood samples or inner tree rings. Thus, it appeared to be of paramount importance to obtain an independent check on the results. This was considered possible using the published ceramic data, as follows.

Figure 3 shows the results of seriating the ceramic data (Georgiev *et al.* 1979) by the CA method. The seriation nicely reconstructs the artifact stratigraphy, with the exception of an incorrect position

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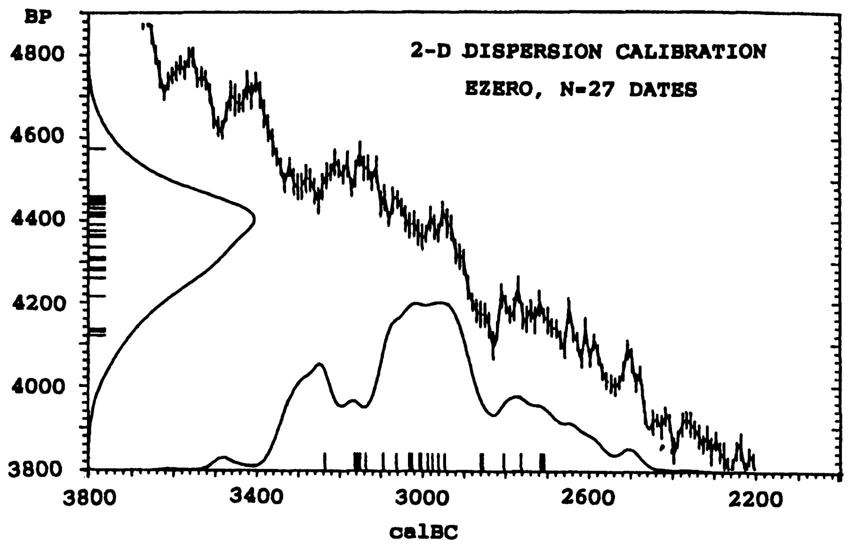

Fig. 1. Calibrated probability distribution for 27 dates (Table 3) of the tell mound at Ezero. The ticks on the ^{14}C scale show the spread of measured ^{14}C ages. This ticks in the cal scale represent the corresponding cal median values, calculated by fitting Gaussian curves to the (partly multimodal) cal distributions of the individual dates. Decadal tree-ring calibration data set UWTEN93.14C (Stuiver and Reimer 1993).

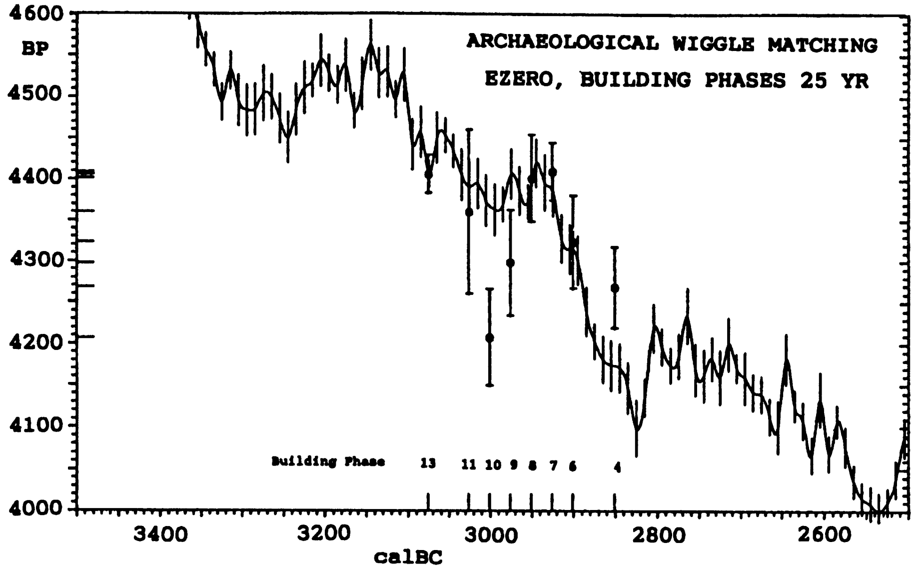

Fig. 2. Archaeological wiggle matching of ^{14}C data on charcoal from building phases 13–4 at Ezero. Average phase length 25 yr. Decadal tree-ring calibration data set UWTEN93.14C (Stuiver and Reimer 1993).

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for the ceramics from phase 9. The ceramics separate into three clusters indicating the existence of a phase-group (or "subperiod") with older ceramic types (phases 13–8), a transitional subperiod (phases 7–6) and a younger subperiod (phases 5–2). The strongest change in the ceramic spectrum occurs in the transition from phase 6 to phase 5. Based on a detailed analysis of the individual ceramic finds, the excavators differentiate subperiods Ezero-A (older phases 13–11) and Ezero-B (younger phases 6–2), with an intermediate subperiod of phases 8–7. Acknowledging the difficulties of stratigraphic analysis, the results of the ceramic analysis (Georgiev *et al.* 1979) and the statistical procedures presented here seem quite concordant.

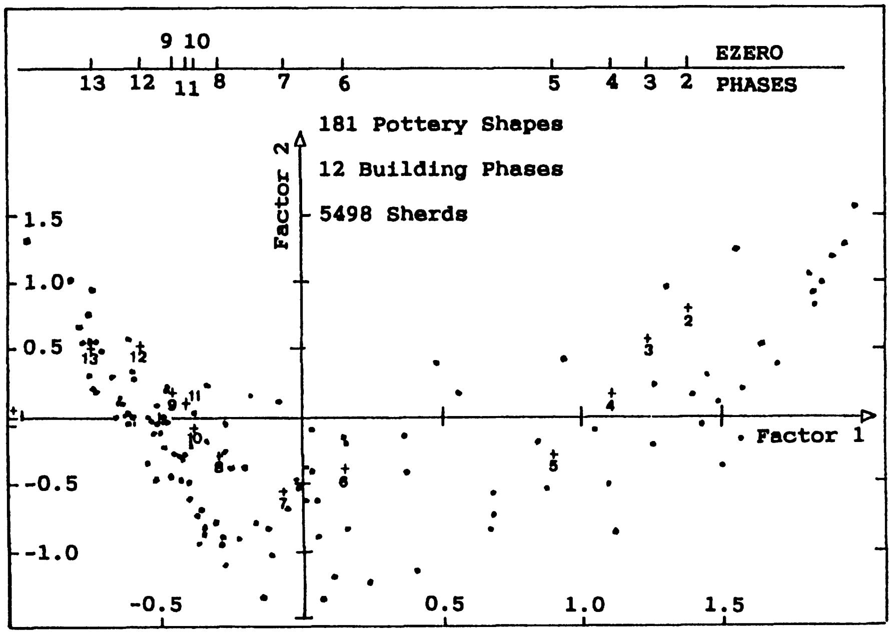

Fig. 3. Results from CA of ceramic data (Georgiev *et al.* 1979) from the EB phases 13–2 at Ezero.

The seriation results allow us to readdress the questions: 1) whether the phase lengths can be assumed equal; and 2) whether the settlement was continuous. Assuming a one-to-one relation between the ceramic "time" scale (factor 1) and calendric time, there are no indications of non-linearities and gaps larger than *ca.* 60 yr for phases 13–6 and 5–2. It is difficult to rule out this possibility in the transition from phase 6–5.

A further check on settlement continuity was to wiggle-match the ^{14}C ages using the seriation results. The archaeological wiggle-matching application, in this case, is to project the CA coordinates of the phases onto the first eigenvector (factor 1 in Fig. 3) and resequence the ^{14}C ages accordingly. This approach changes the position of phase 9 samples and corresponding ^{14}C ages, at the same time introducing phases of unequal length. The phase lengths are thus linearly related to the differences in factor 1 phase coordinates.

Figure 4 shows the "best" results achieved by ceramic seriation of the ^{14}C data for an overall time span of 270 yr, which is equivalent to an average building phase length of 25 yr. Although the chronologies obtained by architectural and ceramic seriation are quite similar for phases 13–6, it is interesting to observe that, for phases 5–2, the ceramic seriation leads to cal ages that are 50–150 yr younger (*cf.* Figs. 2 and 4). This may imply a slowing down of the changes in pottery shapes in phases 5–2, in relation to earlier phases, or a lengthening of building phases 5–2, or both.

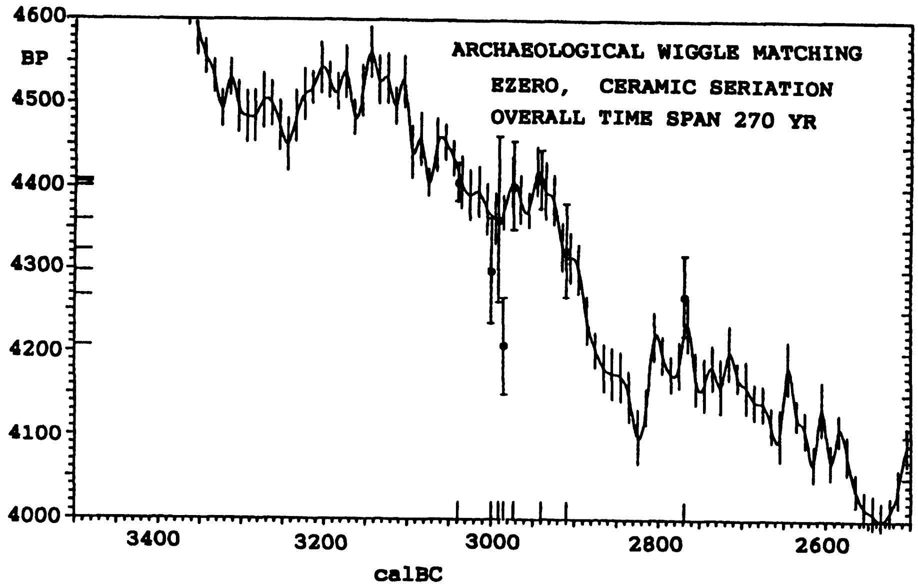

Fig. 4. Archaeological wiggle matching of ^{14}C data on charcoal from building phases 13–5 at Ezero, based on ceramic seriation. Assumed time span 270 yr. Average phase length 25 yr. Error bars ± 1 σ. Decadal tree-ring calibration data set UWTEN93.14C (Stuiver and Reimer 1993).

Troy

The 16-m-deep stratigraphy of Troy covers *ca.* 4 ka of human settlement, from the EB Age to the Byzantine period. In brief, the Hisarlik mound shows a sequence of fortified settlements, which were successively enlarged during the course of time. During the EB period (Troy I), nine consecutive building phases, Ia–Ii (old–young), were identified, each defined by houses with stone foundations and mudbrick superstructures. The ceramics are handmade. During Troy II, the fortifications were repeatedly enlarged. Most remarkable are the central megaron-type buildings, built in Troy IIc and destroyed by fire in Troy IIg (the well-known "burnt city" of H. Schliemann).

The ceramics of Troy II and following phases are largely wheel-made. The wheel was first introduced in Troy IIc. The following settlements of Troy III–V are less well known, due to large-scale leveling operations during the Hellenistic and Roman periods which destroyed large parts of the upper stratigraphy. The Middle Bronze (MB) Age is covered by Troy VI, the later phases of which show increasingly strong connections to the Myceneaen world. Characteristic for Troy VI are different varieties of the highly polished "Gray-Minyan" fabrics, which are extremely difficult to classify. Troy VI ends with large-scale destruction(s), which are often judged as giving Homeric writing a historic background. During Troy VII, a new wave of people, bringing in handmade pottery ("Buckelkeramik"), settled at Troy.

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The general impression of Troy is that a large number of local "floating" architectural and ceramic stratigraphies exist, which should be synchronized as accurately as possible. The present studies concentrate on the ^{14}C dates and stratigraphy of the Troy I period. The dates, measured by the Heidelberg laboratory (Korfmann and Kromer 1993) are arranged in stratigraphic order in Table 2.

TABLE 2. Troy I Radiocarbon Dates Arranged in Stratigraphic Order. After Korfmann and Kromer (1993)

Lab no. (Hd-)	^{14}C age (BP ± 1 σ)	Phase	AWM (yr)	Deposit	Material
13813	3953 ± 49	Ii	0	D2.275	Charcoal
13633	4228 ± 45	Ii	--	D2.82	Charcoal (outlier)
13862	3986 ± 38	Ig–h	50	D2.196	Charcoal
13643	4629 ± 47	Ig–h	--	D2.81	Charcoal (outlier)
13812	4022 ± 31	Ig–h	25	D2.236	Charcoal
13850	4050 ± 50	Ig	40	D3.190	Charcoal
13644	4673 ± 59	If	--	D3.96	Charcoal (outlier)
13627	4740 ± 49	If	--	D3.96	Charcoal (outlier)
13801	4038 ± 59	If	25	D3.105	Charcoal
13848	4026 ± 40	If	25	D3.105	Charcoal
13295	4463 ± 43	If	--	C3.129	Charcoal (outlier)
13291	4620 ± 170	If	--	C3.186	Charcoal (outlier)
13384	4110 ± 44	Ie–f	25	C3.164	Charcoal
13851	4060 ± 50	Ie	25	D3.167	Charcoal
13852	4208 ± 68	Ie	25	D3.138	Charcoal
13929	4185 ± 31	Ic–d	30	D4.379	Charcoal
13618	4108 ± 38	Ic–d	30	C3.223	Charcoal
13619	4288 ± 37	Ic–d	30	C3.223	Charcoal
13751	4182 ± 32	Ic–d	30	C3.201	Charcoal
13931	3786 ± 55	Ic–d	--	D4.215	Charcoal (outlier)
11906	4168 ± 52	Ib–c	30	D4.14	Sediment
12117	5291 ± 97	Ib	--	C3.59	Sediment (outlier)
12059	4156 ± 59	Ia–b	10	D4.118	Charcoal
11935	4316 ± 34	Ia–b	10	D4.38	Sediment
12060	4289 ± 65	Ia	10	D4.129	Charcoal
12061	4177 ± 41	Ia	10	D4.136	Charcoal
11944	4238 ± 37	Ia	10	D4.50	Sediment
11917	4299 ± 42	Ia	10	D4.34/35	Sediment
11945	4315 ± 84	Ia	10	D4.46	Sediment
12058	4215 ± 84	Ia	10	D3.43	Charcoal
12046	2920 ± 86	Ia	--	D3.42	Charcoal

Figure 5 shows the "best" wiggle-matching result achieved after identifying nine outliers (Table 2), for an assumed average length of 50 yr for phases Troy Ia–Ii. The ^{14}C sequence follows the shape of the calibration curve. Tests with shorter and longer phases showed poorer fitting ^{14}C ages. Lengthening the overall sequence has the strongest displacement effect on the oldest and youngest phases. This is understandable because the rms technique in effect identifies a central value for the ^{14}C sequence. The statistical weight of the ^{14}C ages above the calibration curve is balanced by the number below. Although the ^{14}C ages match the calibration curve, one cannot assume an equal length of time for each of the architectural phases, Troy Ia–Ii. Troy Ia is represented by the remains of an

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apsidal stone foundation, the duration of which could easily be > or <50 yr. This foundation is covered by a large rectangular stone building with a different orientation. The existence of a gap between phases Ia and Ib is thus in no way ruled out, and could amount to any number of decades. Such caveats against the hypothesis of an average phase length of 50 yr also apply to the architecture of the following phases.

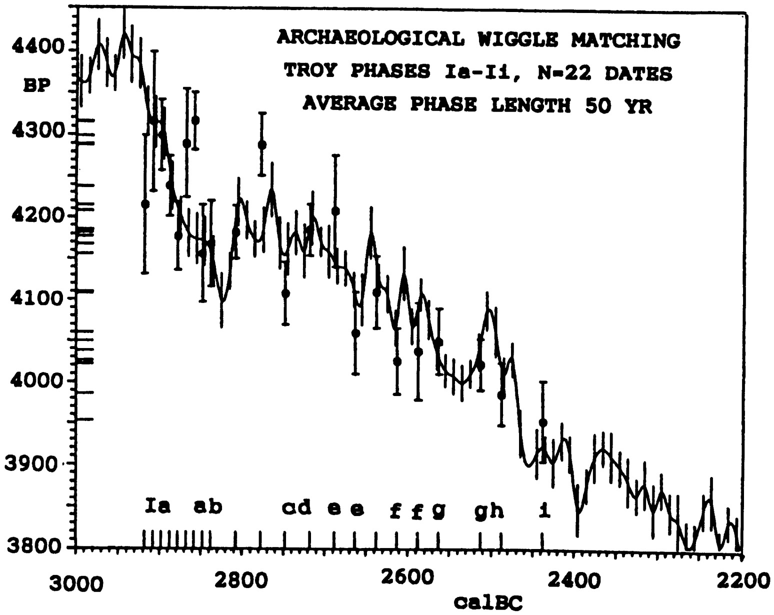

Fig. 5. Archaeological wiggle matching of ^{14}C data on charcoal samples from EB Troy phases Ia–Ii, assuming an average phase length of 50 yr. Error bars ± 1 σ. Decadal tree-ring calibration data set UWTEN93.14C (Stuiver and Reimer 1993).

To check the hypothesis of settlement continuity during Troy Ia-Ii, we again resort to the ceramic data. Using the pottery shape classification system and data of Blegen *et al.* (1950, 1951) for quantitative seriation, it was necessary to derive a scheme of quantifying the pot shape frequencies. A minimum number of 14,917 potsherds were reconstructed.

Figure 6 shows the ceramic seriation as a correlation diagram. The CA coordinates for phases Troy Ia-c are quite similar, as expected for the Troy I (Early) ceramic subperiod. Due to the cluster, the length of these initial phases cannot be established by means of the ceramics, at least using the Blegen *et al.* (1950, 1951) pottery shape classification system. Thus, as for settlement continuity during Troy Ia–c, ceramic seriation offers no additional information for estimating the phase lengths. However, due to the shape of the calibration curve, the age of Troy Ia can be narrowed down to *ca.* 2920 cal BC, simply on the basis of the ^{14}C dates. In comparison, the seriation restricts the possible nonlinearity of the Troy Id-j interval. The Blegen classification system gives a dating accuracy of *ca.* ± 1 building phase (± 50 yr) for this interval.

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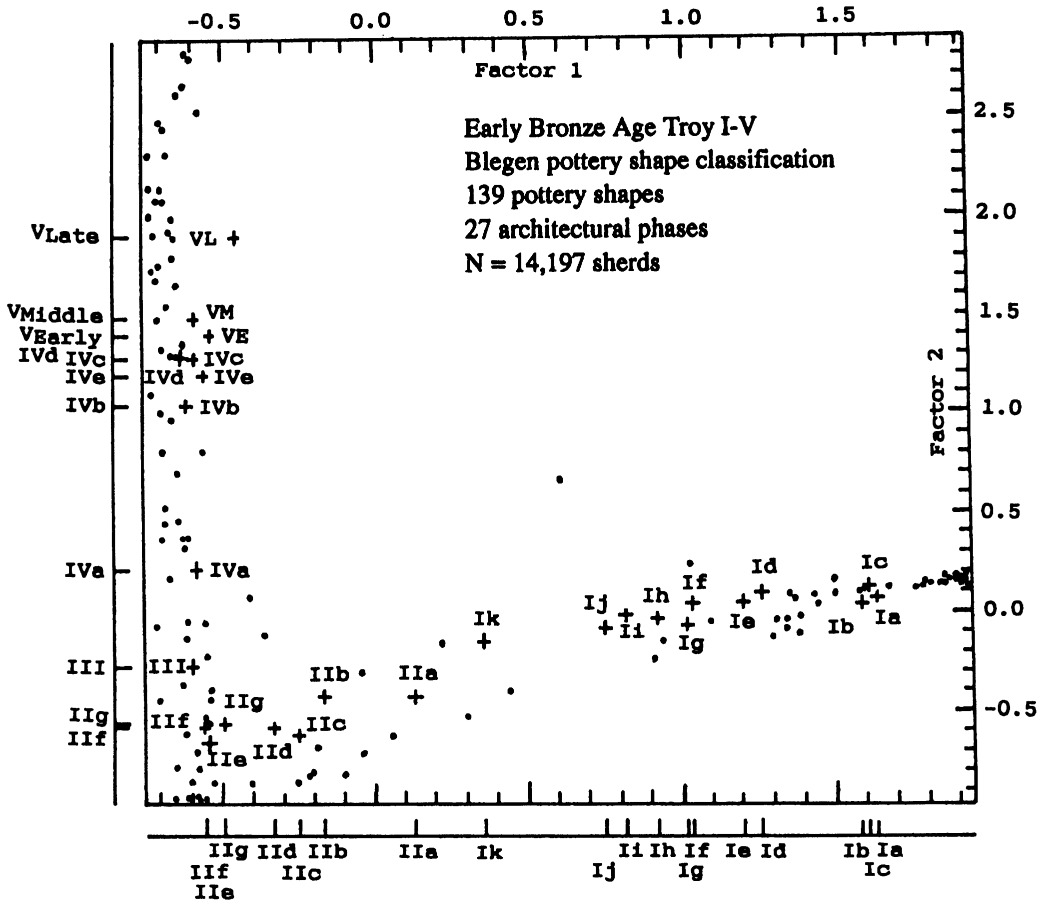

Fig. 6. Results from CA of ceramic data (Blegen 1950, 1951) for EB Troy I–V. Factor 1 represents the ceramic time scale for Troy I–II. Factor 2 represents the ceramic time scale for Troy III–V.

Figure 7 shows the corresponding battleship diagram for most frequent pot shapes. This graph represents 12,202 of the total 14,917 sherds (*i.e.*, 82% of the ceramic data). For the battleship diagram, the precision with which the CA method can reconstruct the stratigraphic sequence of architectural phases was optimized by rotating the coordinate system 45° (Fig. 6).

The seriation results are mostly consistent with the stratigraphic observations of Blegen *et al.* (1950, 1951) and will be discussed in detail elsewhere. Figure 7 demonstrates the amount of reworking of ceramic finds that is encountered in the 20-m tell stratigraphy at Troy. A strong upward movement of the ceramics to higher stratigraphic levels is evident (*e.g.*, for typical Troy I vessel shapes A7, D24, A6, A12 occurring in Troy II-V deposits), in contrast to much fewer downward moving sherds (*e.g.*, Troy II shape A2; Troy IV/V shapes C22, A33, A20).

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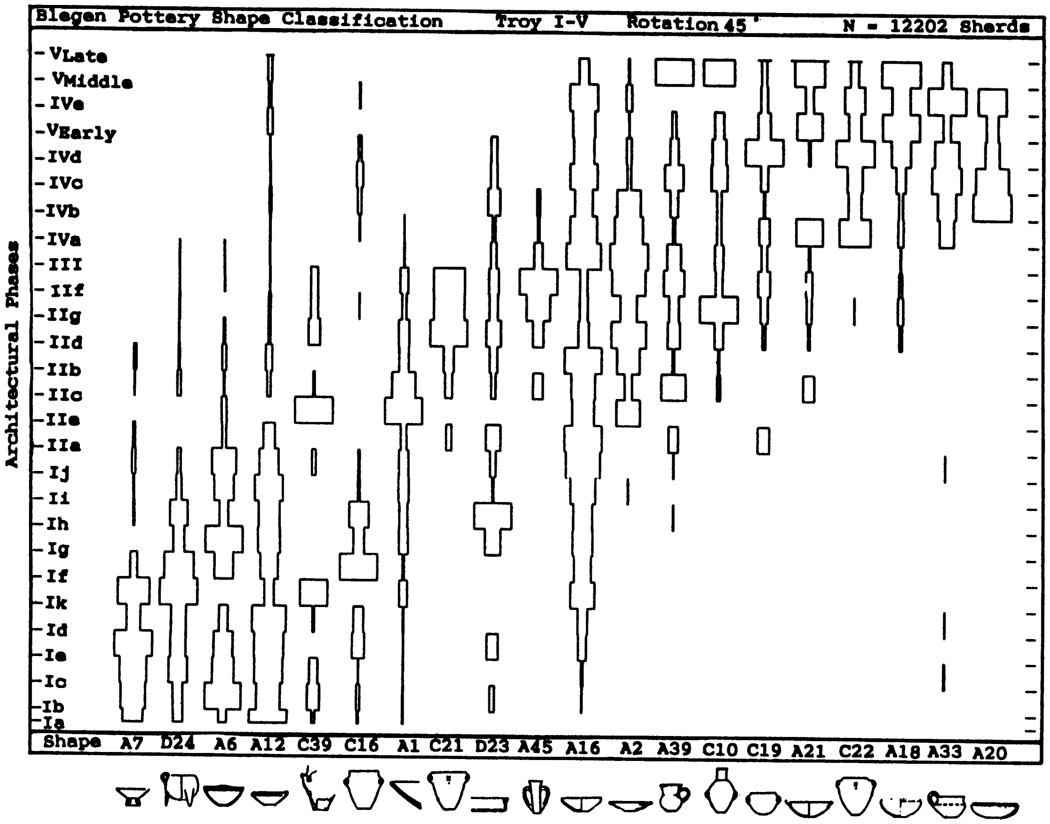

Fig. 7. Battleship diagram of the EB ceramics Troy I–V. Ceramic time runs from bottom left to top right. The diagram shows the percentage variations of pot shapes (A7,. .,A20) in time.

Conclusion

Figure 8 summarizes the results of wiggle matching ^{14}C data from Ezero and Troy. Both the ^{14}C data and the ceramic data are consistent with the hypothesis that the EB settlement sequence at Ezero is continuous, each architectural phase representing *ca.* 25 yr. Wiggle matching of the ^{14}C data by building phase shows that Ezero phases 13–2 date between *ca.* 3100 and 2800 cal BC. Wiggle matching supported by ceramic seriation reinforces these results, although phases 5–2 could be 50–150 yr younger. The wide calibration readings 3400–3100 cal BC and 2800–2500 cal BC initially obtained by 2-D dispersion calibration (Fig. 1) seem improbable on archaeological grounds.

Altogether, the ^{14}C dates from Troy are consistent with the hypothesis that the building phases of Troy I have an average length of 50 yr. With the presently available ^{14}C data, derived *in toto* from potentially multi-annual wood-charcoal samples, the accuracy achievable for the Troy I phases is limited to *ca.* ± 50 yr on the calibration scale.

The Troy I chronology presented in Figure 8 can be tested as follows: additional high-precision ^{14}C measurements by the Heidelberg laboratory on charred wood with 226 tree rings give a tree-ring wiggle-matched cutting date of 2699 ± 15 cal BC for Troy Ib/Ic ± 1 phase (Korfmann and Kromer 1993). This date series was purposely not included in the present analysis. It was used to evaluate the

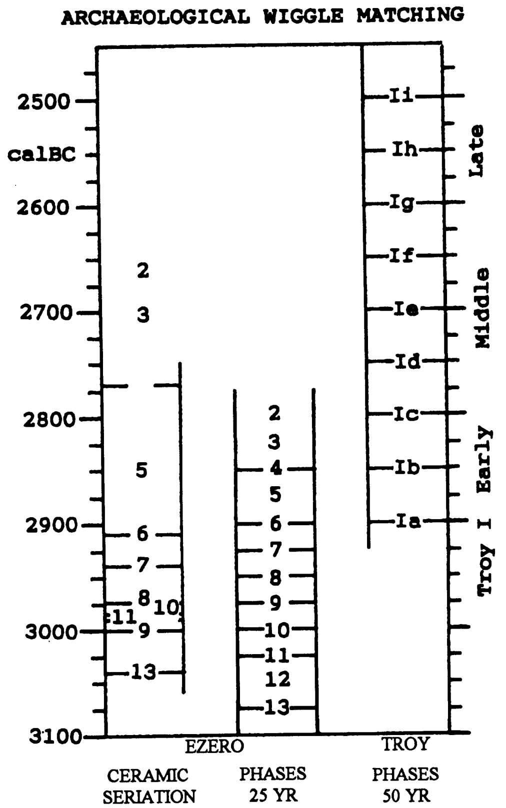

Fig. 8. Synchronization of the EB building phases of Ezero 13–2 and Troy Ia–Ii

accuracy of the methods applied above. The results (*cf.* Korfmann and Kromer 1993, Fig. 23 with Fig. 8 above) differ by a minimum of 20 yr (phase i) and a maximum of 100 yr (phases b/c). These differences can be explained assuming an "old wood" effect for many of the charcoal samples. To lower the dating errors encountered for flat regions of the cal curve, in future research, it may be possible to optimize the biological and taphonomic properties of the archaeological samples submitted for ^{14}C dating. Most useful would be to combine ^{14}C data on carefully chosen bone samples with the results of ceramic seriation for the same excavation units.

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References

Aitchison, T., Ottaway, B. and Al Ruzaiza, A. 1991 Summarizing a group of ^{14}C dates on the historical time scale: With a worked example from the Late Neolithic of Bavaria. *Antiquity* 65: 108–116.

Benzecri, J.-P. 1980a *L'analyse des donnees. I. La Taxonomie.* Paris.

____1980b *L'analyse des donnees. II. L'analyse des correspondences.* Paris.

Blegen, C., Caskey, J., and Rawson, M. 1950 *Troy. Excavations Conducted by the University of Cincinnati 1932–1938,* Vol I: General Introduction: The First and Second Settlements. Princeton University Press.

____1951 *Troy. Excavations Conducted by the University of Cincinnati 1932–1938,* Vol II: The Third, Fourth, and Fifth Settlements. Princeton University Press.

Bojadziev, J. 1992 Probleme der Radiokohlenstoffdatierung der Kulturen des Spätneolithikums und der Frühbronzezeit. *Studia Praehistorica* 11–12: 403.

Bolviken, E., Helskog, E., Helskog, K., Holm-Olsen, I., Solheim, L., and Bertelsen, R. 1982 Correspondence Analysis: An alternative to principal components. *World Archaeology* 14: 41–60.

Breunig, P. 1987 *14C-Chronologie des Vorderasiatischen, Südost- und Mitteleuropäischen Neolithikums.* Bonn, Rudolf Habelt Verlag: 316 p.

Buck, C., Litton, C. and Scott, E. M. 1994 Making the most of radiocarbon dating: Some statistical considerations. *Antiquity* 68: 252–263.

Buck, C., Litton, C. and Smith, A. 1992 Calibration of radiocarbon results pertaining to related archaeological events. *Journal of Archaeological Science* 19: 497–512.

Dehling, H. and van der Plicht, J. 1993 Statistical problems in calibrating radiocarbon dates. *In* Stuiver, M., Long, A. and Kra, R. S., eds., Calibration 1993. *Radiocarbon* 35(1): 239–244.

Easton, D. and Weninger, B. 1993 Troia VI Lower Town – Quadrants I8 and K8: A test case for dating by pottery seriation: *Studia Troica* 3: 45–96.

Ferguson, C., Huber, B. and Suess, H. 1966 Determination of age of Swiss lake dwellings as an example of dendrochronologically calibrated radiocarbon dating. *Zeitschrift Naturforschung* 21a: 1173–1177.

Georgiev, G., Cernych, E., Merpert, N., Katincarov, R., Bacova, E., Kancev, M. 1979 *Ezero. Eine Siedlung aus der Frühbronzezeit.* Sofia.

Geyh, M. 1969 Versuch einer chronologischen Gliederung des marinen Holozän an der Nordseeküste mit Hilfe der statistischen Auswertung von ^{14}C-Daten. *Zeitschrift der Deutschen Geologischen Gesellschaft* 188(2): 351–360.

____1980 Holocene sea-level history: Case study of the statistical evaluation of ^{14}C dates. *In* Stuiver, M. and Kra, R. S., eds., Proceedings of the 10th International ^{14}C Conference. *Radiocarbon* 22(3): 695–704.

Geyh, M. and Maret, P. 1982 Histogram evaluation of C14 dates applied to the first complete Iron Age sequence from West Central Africa. *Archaeometry* 24: 158–163.

Ihm, P. and Groenewould, H. 1984 *Correspondence Analysis and Gaussian Ordination.* Lectures in Computational Statistics 3, Wien-Würzburg.

Jaguttis-Emden, M. 1977 Zur Präzision archäologischer Datierungen. *Archaeologica Venatoria* 4, Tübingen.

Korfmann, M. and Kromer, B. 1993 Demircihüyük, Besik-Tepe, Troia – Eine Zwischenbilanz zur Chronologie dreier Orte in Westanatolien. *Studia Troica* 3: 135–171.

Manning, S. 1995 *The Absolute Chronology of the Aegean Early Bronze Age: Archaeology, Radiocarbon and History.* Monographs in Mediterranean Archaeology 1. Sheffield Academic Press.

Manning, S. and Weninger, B. 1992 A light in the dark: Archaeological wiggle matching and the absolute chronology of the close of the Aegean Late Bronze Age. *Antiquity* 66: 636–663.

Mook, W. 1983 ^{14}C calibration curves depending on sample time width. *In* Mook, W. G. and Waterbolk, H. T., eds., *Proceedings of the Symposium ^{14}C and Archaeology.* Strasbourg, PACT 8: 517–525.

Ottaway, B. 1973 Dispersion diagrams: A new approach to the display of carbon-14 dates. *Archaeometry* 15: 5–12.

Pape, W. 1979 Histogramme neolithischer 14C-Daten. *Germania* 57: 1–51.

Pazdur, M. and Michczynska, D. 1989 Improvement of the procedure for probabilistic calibration of radiocarbon dates. *In* Long, A., Kra, R. S. and Srdoč, D., eds., Proceedings of the 13th International ^{14}C Conference. *Radiocarbon* 31(3): 824–832.

Pearson, G. 1986 Precise calendrical dating of known growth-period samples, using a "curve-fitting" technique. *In* Stuiver, M. and Kra, R. S., eds., Proceedings of the 12th International ^{14}C Conference. *Radiocarbon* 28(2A): 292–299.

Pearson, G. and Stuiver, M. 1986 High-precision calibration of the radiocarbon time-scale 500–2500 BC. *In* Stuiver, M. and Kra, R. S., eds., Proceedings of the 12th International ^{14}C Conference. *Radiocarbon* 28 (2B): 839–862.

Quitta, H. and Kohl, G. 1969 Neue Radiokarbondaten zum Neolithikum und zur frühen Bronzezeit Südosteuropas und der Sowjetunion. *Zeitschrift für Archäologie* 3(2): 233–255.

Robinson, S. 1986 A computational algorithm for calibration of radiocarbon dates. *In* Gulliksen, S. and Nydal, R., eds., The 12th International Radiocarbon Conference, Abstracts. Trondheim, Tipir: 43.

Stolk, A., Hogervorst, K. and Berendsen, H. 1989 Correcting ^{14}C histograms for the non-linearity of the radiocarbon time scale. *Radiocarbon* 31(2): 169–177.

Stuiver, M. and Pearson G. 1986 High-precision calibration of the radiocarbon time-scale, AD 1950–600 BC. *In* Stuiver, M., Long, A. and Kra, R. S., eds., Calibration 1993. *Radiocarbon* 35(1): 1–24.

Stuiver, M. and Reimer, P. 1993 Extended ^{14}C data base and revised CALIB 3.0 ^{14}C age calibration program. *In* Stuiver, M., Long, A. and Kra, R. S., eds., Calibration 1993. *Radiocarbon* 35(1): 215–230.

Suess, H. 1970 The three causes of secular ^{14}C fluctuations, their amplitudes and time constants. *In* Olsson, I. U., ed., *Radiocarbon Variations and Absolute Chronology.* Proceedings of the 12th Nobel Symposium. Stockholm, Almqvist & Wiksell: 595–605.

van der Plicht, J. 1993 The Groningen radiocarbon calibration program. *In* Stuiver, M., Long, A. and Kra, R. S., eds., Calibration 1993. *Radiocarbon* 35(1): 231–237.

van Geel, B. and Mook, W. G. 1989 High-resolution ^{14}C

dating of organic deposits using natural atmospheric ^{14}C variations. *Radiocarbon* 31(2): 151–155.

Ward, G. and Wilson, S. 1978 Procedures for comparing and combining radiocarbon age determinations. *Archaeometry* 20: 19–31.

Weninger, B. 1986 High-precision calibration of archaeological radiocarbon dates. *Acta Interdisciplinaria Archaeologica* 4: 11–53.

____1987 Die Radiocarbondaten. *In* Korfmann, M., ed., *Demircihüyük. Die Ergebnisse der Ausgrabungen 1975-1978* Vol. 2. Mainz, Naturwissenschaftliche Untersuchungen: 4–13.

____1990 Theoretical radiocarbon discrepancies. *In* Hardy, D. A. and Renfrew, A. C., eds., *Thera and the Aegean World III*, Vol. 3: Chronology. Proceedings of the Third International Conference, Santorini, Greece 1989: 216–231.

____1992a (ms.) *Studien zur dendrochronologischen Kalibration von archäologischen ^{14}C Daten*. Ph.D. dissertation. Johann Wolfgang Goethe Universität, Frankfurt am Main.

____ 1992b Fallstudien zur 14C Chronologie in Bulgarien. *Studia Praehistorica* 11/12: 407–422.

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