DENDROCHRONOLOGY AND RADIOCARBON DATING METHODS IN ARCHAEOLOGICAL STUDIES OF SCYTHIAN SITES

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ABSTRACT. We propose a new method of cross-dating the wood samples based on the classical methods of spectral estimation. This method uses the average cross-spectral density as a function of the relative position of the series. Because it is not sensitive to phase shifts in data it is appropriate for cross-dating samples originating from geographically distinct areas.

The accuracy of cross dating depends on the integrity of the samples used, and in the case of well-preserved wood samples, the precision of relative age comparison may reach a single year. The method was tested on two dendrochronological series from Scythian barrows of known age in Southern Siberia: the Pazyryk barrows (the Altai Mountains) and the Dogee-Baary-2 burials (Western Sayan Mountains) separated by 450 km. The analysis has shown that the Pazyryk barrow is younger by 80 ± 4 yr than the Dogee-Baary –2 burials. This result is in agreement with the new chronology of Scythian-related sites suggested for Southern Siberia and Central Asia.

INTRODUCTION

The origin, evolution, and spread of the Scythian nomadic culture in Europe and Asia are key issues in modern archaeology. Archaeological typological methods make possible an estimate of the relative duration of chronological intervals notable in this ancient culture. However, the chronologies based on the similarities of artifact styles imply considerable uncertainties related to the origin of certain styles, the rate of their spread, and the longevity of their use (Deetz and Dethlefsen 1965).

Although numerous date lists related to Iron Age sites have been published in recent years, the exact ages of these cultures remain problematic. The chronology of Eurasian cultures still largely relies on the cross dating of relevant artifacts and art styles. Hall (1997) notes that this chronology may be satisfactory for the Sarmatians and Scythians in the Black Sea area, but it is highly problematic for cultures of the Altai Scythians and Tagar that contain few dateable imports.

Radiocarbon measurement of archaeological samples remains the most reliable way of establishing an absolute age of historical and cultural sites. To find an exact date of an archaeological sample, one has to calibrate the measured ^{14}C age with the use of a calibration curve. Because of the intricate contour of certain sections of the calibration curve, the dates thus obtained are often ambiguous. This is particularly the case for plateaus occurring on the calibration curve, which results in very wide time ranges of the calibrated age. However, such complications in ^{14}C dating may be overcome by means of a “wiggle matching” technique, in which the ^{14}C ages of several samples from a single wood specimen are projected on the calibration curve. For a successful application of this technique one needs to obtain ^{14}C measurements with an accuracy comparable to the resolution of the calibration curve.

A different approach to dating the archaeological specimen consists in the use of cross-dating method. The advantage of cross-dating the wood specimen is its high accuracy, which in favorable cases may be close to a single year. The cross dating is particularly advantageous when the age of

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RADIOCARBON, Vol 43, Nr 2A, 2001, p 417–424
Proceedings of the 17th International ^{14}C Conference, edited by I Carmi and E Boaretto

the studied sites differs by only a few years. This approach is useful for dating the cultures and historical sites located in neighboring geographical regions and in a similar environment.

In this paper a new approach is suggested, aimed at the correlation of dendrochronological series, with the use of computers and the methods of mathematical statistics. This method was applied for cross-dating Scythian sites in Southern Siberia.

Cross Dating

Cross dating is basic procedure in tree-ring analysis. The concept refers to the general year-to-year agreement observable in the variations of tree-ring series at different sites. According to Fritts (1976), the observed synchrony is the result of the limiting effect of climate variations on the tree growth. The similarity in the ring-width pattern is correlated with seasonal variation in macro-climatic factors that are closely coupled with local environmental conditions controlling the physiologic ring growth (Fritts and Swetnam 1989).

In practice, the cross dating includes the establishment of a matching of ring-width pattern in the studied specimen. This eventually leads to the construction of local or regional dendrochronologies (Pilcher 1990; Fritts 1976; Schweingruber 1988).

Early studies relied almost exclusively on visual observations of the timber samples. The cross-dating either of skeleton plots or the entire patterns can be obtained visually: all ring patterns in the entire sample being matched ring by ring. Visual matching and cross dating are usually chosen when living trees are dealt with or when the date the sampling is known. The same methods may be also applied to the samples of historical and prehistorical age, but in that case the use of mathematical criteria of similarity is preferred, for the reason of saving time and for avoiding a subjectivity. Huber (1935) introduced a criterion for the assessment of the measure of visual agreement. He counted the number of cases where two tree-ring curves under comparison show a simultaneous increase or decrease. For the two curves at random position one expects 50% agreement or disagreement, respectively. The standard deviation for this mean value depends on the length of the overlap of the two curves under comparison (Eckstein and Bauch 1969). Even with the availability of computers, this kind of checking of visual agreement is still in use, although more powerful statistics can now be applied, for example, the correlation calculations (Baillie and Pilcher 1973). Since then, various methods have been developed to analyze the statistical properties of tree-ring series (Baillie 1982; Wigley et al. 1984; Briffa and Jones 1990).

The cross dating in archaeology features specific characteristics. Above all, the age difference between the samples may reach tens of years; therefore the visual comparison approach is both time-consuming and inaccurate. Besides, additional difficulties arise if the samples are not well preserved. It should also be noted that the present-day approach to the study of dendrochronological series based on visual comparison of samples is not convenient to formulate as a computer algorithm. In this paper, we suggest and describe the cross-dating methods, which include both the method of sample comparison and the estimation of similarity. Based on classical spectral analysis, it is adapted for use as a computer technique that considerably speeds up the cross dating.

METHODS OF INVESTIGATION

Dendrochronological series in archaeology may originate from regions separated by hundreds of kilometers. Hence the similarity of the series, belonging to the same time interval but coming from different geographical areas, may be masked by the differences in phase and amplitude characteristics, as the climate in those areas may have developed asynchronously. In addition, the differences in the conditions of growth and the local environment could enhance the disagreement. Therefore for satisfactory correlation of dendrochronological series it is necessary to assume that samples come from sites located in neighboring geographical regions with similar environment. In the general case, one may be confident that the comparison is successful if the method in use is not sensitive to a difference in phase characteristics of the series.

The method proposed here is based on the coherence estimation of series for various relative positions. The coherence C_w of series *A* and *B* for the frequency w is defined (see, e.g. Marple 1987) as

$$C(\omega)=|P_{AB}(\omega)| / (P_A(\omega) P_B(\omega))^{1/2}. \quad (1)$$

The P_A and P_B power spectral density for these series, P_{AB} cross power spectral density. To decrease the influence of noise in spectral estimation one must use a covariance window (Marple 1987). The denominator in equation (1) is a normalizing quantity, one can say that the coherence is a suitably normalized cross-spectral density. The variable $C(\omega)$ lies in the range from 0 to 1 depending on the coherence of series. A more important use of the coherence is to identify a common sequence in two different series. It is however more effective to use the average value in dendrochronological investigations

$$C_{av}=\Sigma_w |P_{AB}(\omega)|/(\Sigma_w P_A(\omega)\Sigma_w P_B(\omega))^{1/2}. \quad (2)$$

C_{av} will be called the average coherence.

Assessment of the Method

The Use of Modern Specimens

Testing of the methods was carried out on several series (Table 1) from Lithuania and Russia (Karelia), obtained in the dendrochronological laboratory in Kaunas (Bitvinskas 1974). To test the method, the average coherence was calculated for several pairs of series. The results of the analysis for two pairs of series from Table 1 are presented in Figure 1 (a, b). It was established that the "Lithuania 1" and "Lithuania 2" series have a zero shift, which agrees with its expected value. For the "Karelia 1" and "Karelia 2" series, the relative shift is equal to 2 years, while the expected shift is zero. From detailed considerations, the difference between the estimate and the expected value can be apparently explained as a result of a miscalculation in the counting of tree rings in the sample.

Table 1 Dendrochronological series used for testing

Region	Index	Time interval (AD)	Length (yr)
Karelia	1	1600–1739	140
Karelia	2	1600–1739	140
Lithuania	1	1806–1961	156
Lithuania	2	1814–1961	148

To establish the significance of the results, the properties of the series were compared with that of random series. The mean C_{av} value and two levels for these sequences were calculated. The probability of exceeding the first and second levels are 0.05 and 0.005, respectively. The horizontal dashed lines on the diagrams refer to these levels. The dotted line refers to the mean of the C_{av} value. The result is considered as significant if the maximum on the diagram is located above the upper dashed line (significance value exceeding 0.995).

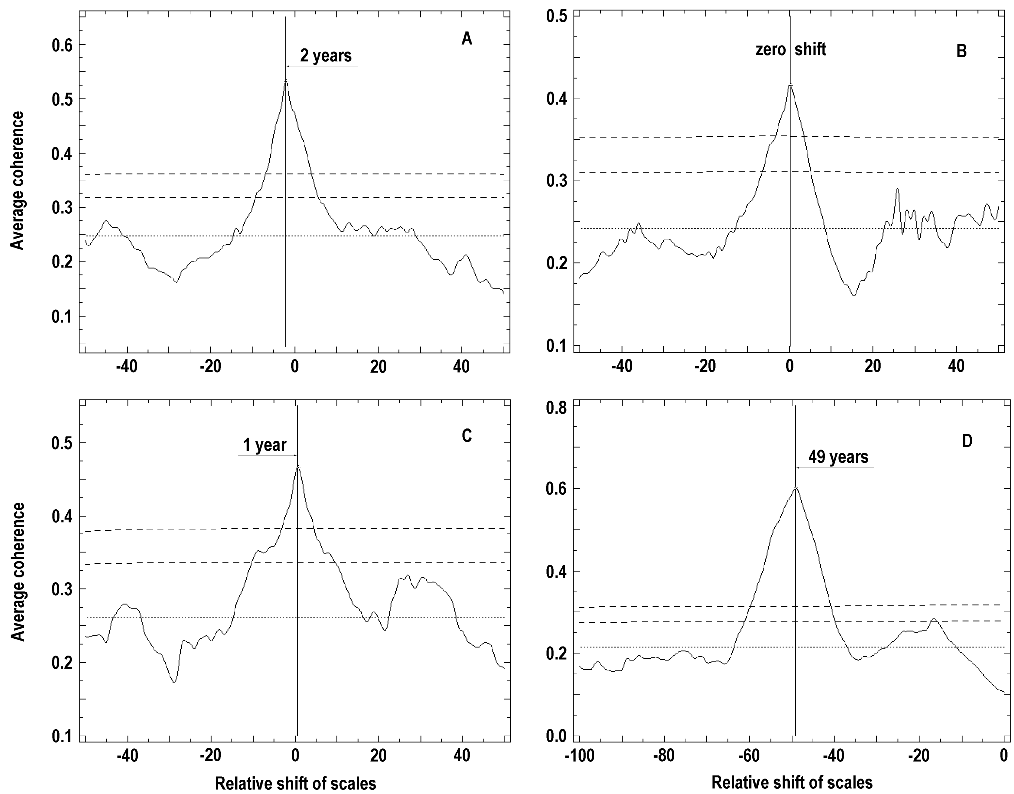

Figure 1 The average coherence is considered as a function of the relative shift of dendrochronological series. A – "Karelia 1" and "Karelia 2", B – "Lithuania 1" and "Lithuania 2", C - "Pazyryk 2" and "Pazyryk 1", D - "Pazyryk 2" and "Pazyryk 5". The dotted line refers to the mean of C_{av} value defined by (2) and is computed for a random series. The horizontal dashed lines on the diagrams refer to two levels. For a random series the probability of exceeding first and second levels are 0.05 and 0.005, respectively. A result is considered as significant if the maximum on the diagram is located above the upper dashed line (significance value is more than 0.995). The relative positions of the compared series are shown on the horizontal axis.

The Use of Archaeological Specimens

For dendrochronological research we used carefully selected series of specimens. The chosen samples came from geographically related areas with a similar environment. Since the series used in dendrochronology are usually of better quality then those used in archaeology, the need to test the methods on archaeological specimen was evident.

The "elite" barrows of Arzhan, Tuekta, and Pazyryk, located in the Sayan-Altai Mountains of southern Siberia, belong to the Scythian Culture (the end of the 9th to the middle of the 3rd centuries BC). We have focused on the Pazyryk barrows, which form a group of five well-preserved burial mounds. Earlier dendrochronological investigations of the Pazyryk barrows were completed in the 1950s (Zamotorin 1959). Barrows 1, 2, and 5 have been better studied than the other barrows. We used our methodology to determine relative age of these three barrows. Figure 1 (c, d) shows the corresponding diagrams. Table 2 presents our results and the original results by Zamotorin. Differences of as little as 1–2 years can be identified by means of cross dating. In conclusion, one can ascertain that the cross-dating errors for well-preserved wood specimen do not exceed 2 years.

Table 2 Relative chronology of Pazyryk barrows

Author	Pazyryk #1	Pazyryk #2	Pazyryk #5
Zamotorin 1959	–48	–48	0
Our results 2000	–50	–49	0

Determination of Comparative Ages for the Pazyryk and Dogee-Baary-2 Barrows

The Dogee-Baary-2 burial mounds, which belong to the group of Sayan-Altai barrows, are located in Tuva (western Sayan Mountains), 450 km east of the Pazyryk. Their exact age is essential for the chronology for the entire cluster of the Sayan-Altai barrows. To develop this chronology with the use of suggested methodology, we have chosen barrows 1 and 2 in the Pazyryk Group and barrows 8 and 12 in the Dogee-Baary-2 Group, all these sites being rich in wood samples. Tables 3 and 4 present the main properties of the series.

Table 3 Dendrochronological series of the Pazyryk Group

Series	Length (yr)	Barrow index	Relative position
90002	116	1	5
90003	179	1	–20
90004	237	2	–7
90005	102	2	0
90006	176	2	–12
mpaz2	243	1 and 2	0
zpaz2	204	2	0

Table 4 Dendrochronological series of the Dogee-Baary-2 Group

Series	Length (yr)	Barrow index	Relative position
90221	157	8	–2
90222	141	8	0
90224	136	8	–2
90225	164	8	0
90227	152	8	–2
90229	141	8	–9
90248	208	12	–10

The mpaz2 series is the combination of 90002–90006 series. The zpaz2 series was found by summation of the five series of Pazyryk No. 2 that were obtained by Zakharieva (1974) and are not included in Table 3. All other series used here have been obtained in the Institute of Archaeology and Ethnography (Siberia, Novosibirsk)

Before comparing the series we have carried out a preliminary processing by eliminating the growth curve. The determination of trend shape was made with the use of the method of least squares. For mathematical representation, the trend was described by a cubic spline with equidistant nodes. The distance between the nodes varied from 10 to 30 years.

We carried out the paired comparison of the Dogee-Baary-2 and Pazyryk series. After preliminary processing we calculated the average coherence of the paired series depending on the value of relative displacement. The comparative position of the series was determined by the maximum of the average coherence. The location of a significant maximum on the diagram shows the comparative age of the series. Table 5 shows the relative positions of the series under investigation. It should be noted that all 25 pairs of the series represented in Table 5 were compared. However, the relative positions of only 8 pairs were confidently identified. This may be explained by the poor preservation of the Dogee-Baary-2 wood samples; the signs of deformation and structural alterations were visible in the cross-sections. Although the comparative age of the monuments does have a practical meaning, it cannot be extrapolated to individual wood samples taken from these sites. The series being a numerical representation of the samples includes incomplete information about the outer layers of logs. Hence to determine the comparative age of the two monuments we need to sum up the data of Tables 3, 4, and 5. Table 6 shows the data on the relative age of the Dogee-Baary-2 and Pazyryk Groups. The estimate was obtained by means of comparison of eight pairs of samples. According to these investigations, Barrow 8 of Dogee-Baary-2 Group is older than Barrow 2 of the Pazyryk Group by 80 ± 4 yr (1 σ).

Table 5 Relative position of the series of Dogee-Baary 2 and Pazyryk 1and 2 Barrows

Series	90003	90004	90006	mpaz2	zpaz2
90221		–72		–78	
90224					–76
90227	–68	–73			
90229	–72		–79		
90248		–84			

Table 6 The comparative construction date of Dogee-Baary 2 Group (Barrow 8) and Pazyryk Group (Barrow 2*)*

Compared series		Relative construction dates	Deviation from average
90221	90004	–77	+3
90221	mpaz2	–76	+4
90224	zpaz2	–74	+6
90227	90003	–86	–6
90227	90004	–78	+2
90229	90003	–83	–3
90229	90006	–82	–2
90248	90003	–81	–1

DISCUSSION AND CONCLUSIONS

The absolute chronology of historical and cultural sites is a very important aspect in archaeological research. The earlier studies of the Sayan-Altai Scythian sites left unanswered many questions concerning their chronological position. That is also the case of the Pazyryk barrows, which are the key sites. The traditional dating suggests that the Pazyryk barrows were constructed in the 5th century BC (Zaitseva et al. 1997, 1998). This estimation of age is based on the art-historical comparative analysis of the objects from these burials (Bunker 1991; Kawami 1991; Lerner 1991). It is equally probable that the construction date of these barrows occurred at the end of 4th to the beginning of the 3rd centuries BC (Bunker et al. 1991; Chugunov 1993). The most recent results of ^{14}C dating of Pazyryk Barrow 2 attributes its construction date to the beginning of the 3rd century BC (F G McCormac and J P Mallory, personal communication 1999). We have carried out the ^{14}C age measurements of the D-5 sample from Pazyryk Barrow 2 (Le-5558–Le-5563). The log was split in 6 pieces, each one including 20 tree rings. To determine the absolute age of the sample, the ^{14}C dates were calibrated with the use of the bidecadal calibration curve (Pearson and Stuiver 1993; Stuiver and Pearson 1993). The position of the experimental points relative to the calibration curve was determined by means of minimization of χ^2 statistics (Zaitseva et al. 1998). According to our estimation the construction date of Pazyryk Barrow 2 is 300 BC with an error of 25–35 yr (2 σ). See Figure 2 for details. Only a few ^{14}C dates are available for the Dogee-Baary-2 burials (Sementsov et al. 1998; Görsdorf et al. 1998). According to these data, the construction date of the tombs is the end 6th to the beginning of the 4th century BC. Thus the results of the comparative analysis of the age of the Dogee-Baary-2 and Pazyryk sites are in agreement with the results based on ^{14}C dating. The construction date of Barrow 8 of the Dogee-Baary-2 Group should be attributed to the first third of the 4th century BC. Indirectly obtained evidence confirms this new assessment of the absolute age of the Pazyryk barrows and supports the revised chronology of Iron Age for the entire area of southern Siberia and central Asia.

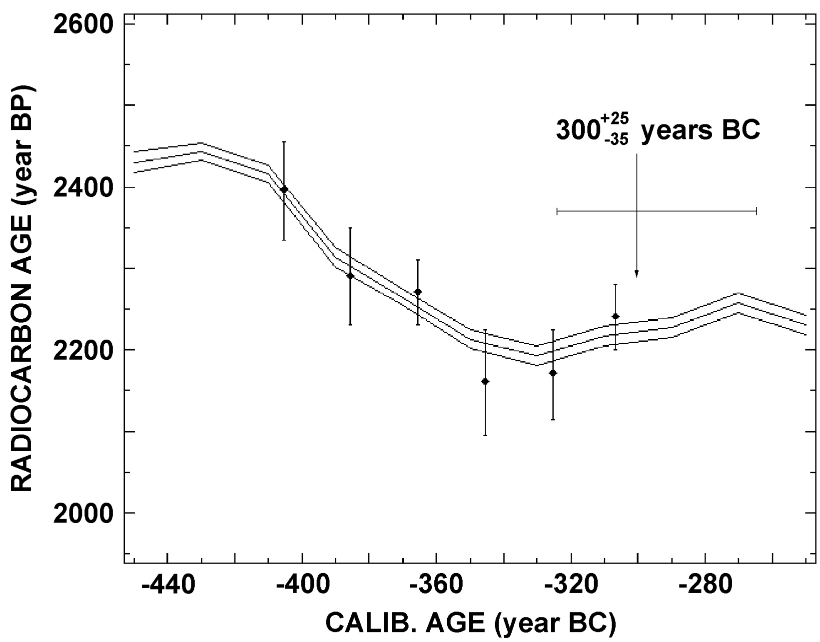

Figure 2 Results of the ^{14}C age measurements of D-5 sample of Pazyryk barrow 2 (Le-5558--Le-5563). The log was split in 6 pieces, and each included 20 tree rings. To determine the absolute age of sample the data of ^{14}C age were compared to the bidecadal calibration curve (Pearson and Stuiver 1993; Stuiver and Pearson 1993). The position of experimental points relative to the calibration curve was determined by means of minimization of χ^2 statistics (Zaitseva et al. 1998). According to our estimation the construction date of Pazyryk barrow 2 was about 300 BC with error 25–35 yr (2 σ).

ACKNOWLEDGMENT

This research is supported by Russian Foundation of Basic Research, Grant No. 99-06-80231 and INTAS, Grant No. 97-20362.

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