GEOCHRONOMETRIA Vol. 20, pp 61-68, 2001 – *Journal on Methods and Applications of Absolute Chronology*

TREE-RINGS, "WIGGLE MATCHING" AND STATISTICS IN THE CHRONOLOGICAL STUDIES OF SCYTHIAN AGE SITES IN ASIA

S.S. VASILIEV [1], N.A.BOKOVENKO[2], K.A.CHUGUNOV[3], V.A.DERGACHEV[1], A.A. SEMENTSOV[2], JU. SLJUSARENKO[4], G.I. ZAITSEVA[2]

[1] *Ioffe Physico-Technical Institute, Russian Academy of Sciences, Politechnicheskaya 26, 194021 St.Petersburg, Russia*

[2] *Institute for History of Material Culture, Russian Academy of Sciences, Dvortsovaya Naberezhnaya 18, 191186 St.Petersburg, Russia (e-mail: ganna@mail.wplus.net)*

[3] *Institute of Cultural and Natural Heritage, St.Petersburg, Russia*

[4] *Institute for Archaeology and Ethnography, Novosibirsk, Russia*

Key words: TREE-RING CHRONOLOGY, CROSS-DATING, RADIOCARBON, WIGGLE MATCHING METHOD, SCYTIAN EPOCH, EURASIA

Abstract: A new method of cross-dating of wood samples is suggested. Based on the classical methods of spectral estimating, it uses the average cross-spectral density as a function of relative position of series. This procedure being not sensitive to phase shifts in data may be instrumental for the cross-dating of samples originating from different areas. The method was tested on Scythian tombs located in Southern Siberia, Central Asia and Kazakhstan, with the emphasis on the "Royal" barrows which included well preserved wood structures. For well-preserved timber samples, the accuracy in relative age estimations can reach a single year. The wiggle matching method has been used for a reliable assessment of the calendar-scale time.

1. INTRODUCTION

The origin, evolution and spread of the Scythian nomadic culture in Europe and Asia remain the key issues in the Iron Age Archaeology. Methods based on archaeological typology enable one to estimate relative duration of certain periods identifiable within this culture. Yet the chronologies solely based on the similarities of the artefact styles imply considerable uncertainties, stemming from the origin of certain styles, the rate of their spread and the longevity of their being in use (Deetz and Dethlefsen, 1965).

Although several date-lists of the Iron Age sites have been published in recent years, the exact age of particular cultures remains obscure. The establishment of calendar time-scale chronology with use of radiocarbon-dated Scythian sites in the span between the 9th and the 3rd centuries BC poses serious problems. The radiocarbon measurement of archaeological specimens remains the main instrument of absolute dating. To obtain a calendar age, the radiocarbon dates of archaeological objects under investigation should be compared with the calibration curve. Due to the non-linear course of some sections of the calibration curve, this technique often produces ambiguous results. This ambiguity may be avoided with use of 'wiggle matching' methodology: the comparison of radiocarbon ages of several samples obtained from a single specimen of wood with the calibrating curve. For reliable results, the accuracy of radiocarbon measurements should be comparable with the resolution of the calibration curve. The use of alternative dating techniques is also important as an independent control.

In addition to that, the cross-dating of archaeological samples is highly instrumental. The cross dating of samples of wood allows one, in favourable cases, to obtain the accuracy of a single year. The cross-dating is particularly important when the age difference of investigated sites is very small. This approach is also very useful when the cultures and sites are located in neighbouring geographical regions and in similar climatic setting.

In this paper a new approach for the comparison of tree-ring series is suggested with use of computer techniques and methods of mathematical statistics. These methods are applied with the aim of cross-dating the Scythian sites in Southern Siberia.

2. CROSS-DATING

Cross-dating is the basic principle in tree-ring analysis. This concept refers to the general year-to-year agreement observable in the variations of tree-ring series obtained for different sites. According to Fritts (1976), the synchrony can be shown to stem from the limiting effect of variations in climate on the tree growth. The similarity in ring-width pattern is correlated with seasonal variations in macro-climatic factors that are closely coupled with local environmental conditions controlling the physiological processes essential for the ring growth (Fritts and Swetnam, 1989).

In practice, the cross-dating includes the matching of ring-width patterns among the specimens. At the final stage, the area or regional chronologies are developed (Pilcher, 1990). The cross-dating method has been described in several publications (e.g., Fritts, 1976; Pilcher, 1990; Schweingruber, 1988).

The earlier works relied almost exclusively on visual observation of timber samples. The cross-dating either of the skeleton plots or of the whole patterns can be done visually: the ring patterns match ring-for-ring up to the end of the samples. The method of visual matching and cross-dating is chosen when the living trees with known date of sampling are investigated. When dealing with historical and prehistorical samples, the correct matching positions may be established visually as well, but in this case the use of mathematical quantification of similarity criteria is a matter of time saving and avoidance of subjectivity. Huber (1943) introduced a formal measure to check the visual agreement. He counted the number of cases where two tree-ring curves under comparison increased or decreased together. For 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 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, as, for example, the calculations of correlation (Baillie and Pilcher 1973). Since then vari-

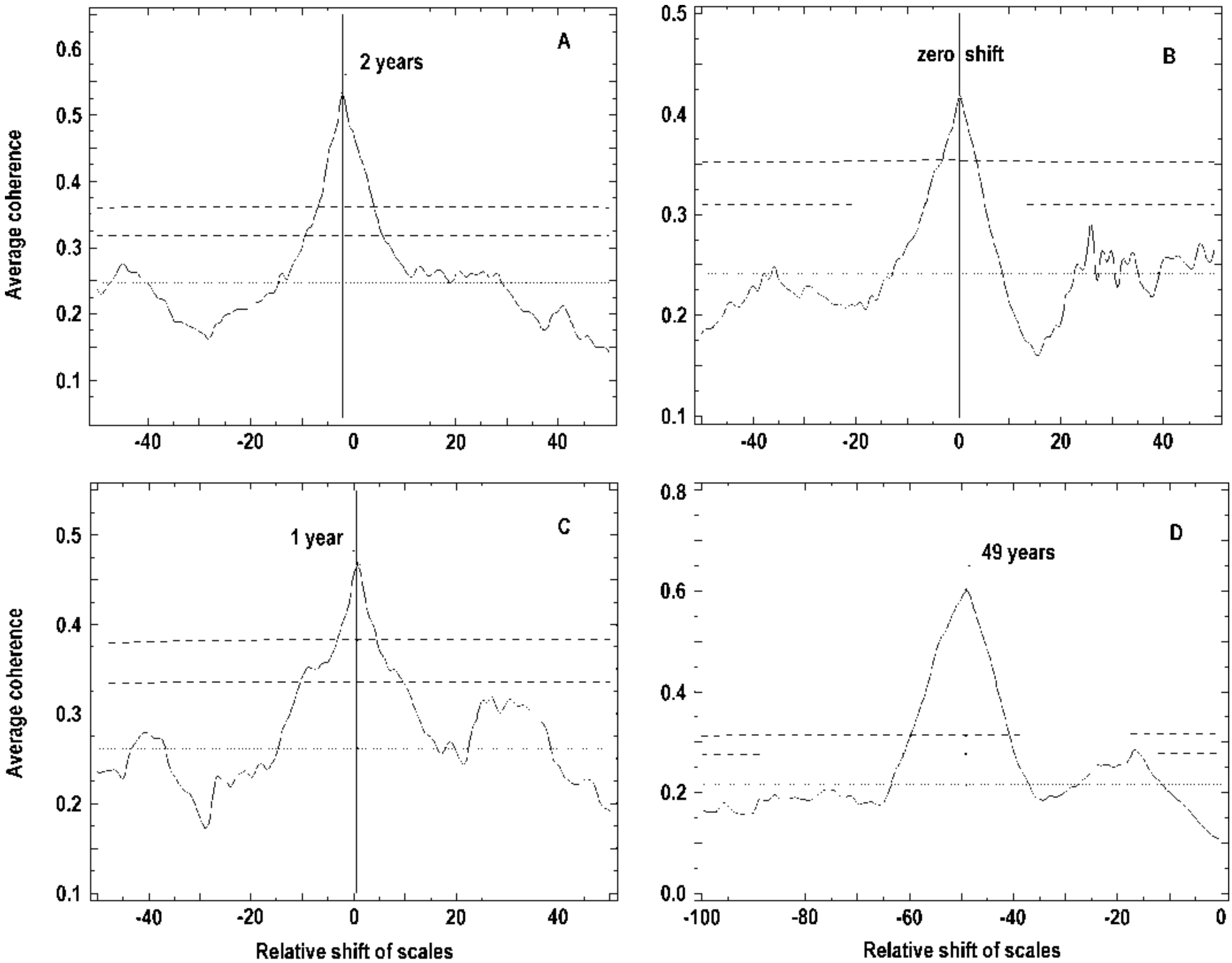

Fig.1. *The average coherence as the function of a relative shift of dendrochronological series. A – 'Karelia 1' and 'Karelia 2', B – 'Lithuania 1' and 'Lithuania 2', C –.'Pazyryk 2' and «Pazyryk 1», D – «Pazyryk 2» and «Pazyryk 5». There are designated three horizontal lines on the diagrams: a dotted and two dashed ones. The dotted line is referred to the mean of* C_{av} *value defined by (2.2) and is computed for random series. The horizontal dashed lines on the diagrams refer to two levels. For random series the probability of exceeding first and second levels are 0.05 and 0.005. A result is considered as significant if the maximum on the diagram is located above the upper dashed line (significance value is more 0.995). Relative positions of compared series are indicated on the horizontal axis.*

ous methods have been developed to analyse the statistical properties of tree-ring series (Baillie, 1982; Wigley *et al.*, 1984, Briffa and Jones, 1990).

In archaeology the cross-dating has several specific characteristics. The reliable estimation of age difference between the samples lies in the order of tens of years, besides that the visual comparison proves to be both time-consuming and ambiguous. Additional difficulties arise when samples are badly preserved. It should also be noted that present-day approach to the study of dendrochronological series, based on the visual comparison of samples, is not appropriate for the development of an algorithm for computer analysis. In this paper we suggest a cross-dating method, which includes both the sample comparison and the estimation of similarity for the series analysed, based on the classical spectral analysis. This method is convenient for the use of computer techniques that speed up considerably the cross-dating.

The methods proposed here is based on coherence estimations of series for various relative positions. The coherence $C(\omega)$ of series A and B for the frequency ω is defined (Marple, 1987) as

$$C(\omega) = |P_{AB}(\omega)| / [\, P_A(\omega)\, P_B(\omega)\,]^{1/2}. \qquad (2.1)$$

The P_A and P_B are the power spectral densities for the series, P_{AB} is the cross power spectral density. To reduce the influence of noise in the spectra, a covariance window can be used (Marple, 1987). Since the denominator in equation (2.1) is a normalising factor, one can expect that the coherence is suitably normalised cross-spectral density. The variable $C(\omega)$ varies from 0 to 1, depending on the coherence amount of the frequency between channels. The most important use of the coherence consists in establishing a common sequence in two distinct channels. The average value

$$C_{av} = <|P_{AB}(\omega)|>(<P_A(\omega)>\cdot< P_B(\omega)>)^{1/2}\ , \qquad (2.2)$$

where < > denotes frequency averaging, can be effectively used in dendrochronological investigations. Herewith C_{av} is called average coherence.

This method was first tested by Dergachev and Vasiliev (2000) on several series from Lithuania and Russia (Karelia) (Bitvinskas, 1974). The average coherence was calculated for several pairs of series. The results for two pairs (**Fig. 1**) show the series "Lithuania 1" and "Lithuania 2" having the zero relative shift, in agreement with the expectation. For the series of "Karelia 1" and "Karelia 2" the relative shift equals to 2 years, while the expectation is zero. As follows from the detailed analysis, the difference between the estimated and the expected results can be attributed to a miscalculation in the numeration of tree rings in the sample studied.

To assess the significance of the result, the series were compared with uncorrelated random sequences, and the values of C_{av} were compared with 2σ and 3σ deviations in the random sequences. The probability of exceeding the two levels are 0.05 and 0.005, if the correlation implied by C_{av} is due to chance. These levels are shown with horizontal dashed lines in **Fig. 1** (A-D). The dotted line shows the mean of C_{av} value. The result is considered as significant if the maximum value of C_{av} is above the upper dashed line (significance of more than 0.995).

3. WIGGLE MATCHING

Due to the environmental conditions, timber remains from the barrow construction of the Scythian sites in Siberia and Central Asia were in a good state of preservation and could be used both for the tree-ring chronology and radiocarbon dating. Samples of timber to be used for dendrochronological analysis are normally carefully selected. These samples should originate from the same area and a similar environment.

The first group of samples selected for the tree-ring analysis derives from the famous 'Royal' Scythian barrows in the Altai Mountains, Pazyryk Barrows No. 2 and 5. These barrows play a key role in the chronological investigations for the entire Eurasian Scythia. In the1950s I. Zamotorin (1959) developed a floating tree-ring scale for the Pazyryk group (Zakharieva, 1974). A new approach to the tree-ring study is based on the coherence estimation of the series in various relative positions. The most important element of the method consists in the possibility of identifying a combined information in two different series, of using the coherence to identify a common sequence in two different channels and of using the average value in tree-ring investigations. The comparison of the results obtained by the methodology suggested and the original data by I. Zamotorin shows a good agreement of the series, the age differences being only 1-2 years. This approach has been used to identify the relative position of the Dogee-Baary-2 burial mounds, which belong to the Sayan-Altai Group in Tuva (The Western Sayan Mountains), 450 km east of the Pazyryk. According to these investigations, Barrow No. 8 of Dogee-Baary-2 Group is older than Barrow No. 2 of Pazyryk Group by 80±4 years (1σ).

As mentioned above, the tree-ring chronology created for the elite Scythian barrows is the floating one. The principle aim of the ongoing research consisted in, first, defining the zero position for the tree-ring floating scale, and, secondly, estimating the 'real' calendar age of the investigated barrows. For these aims the „wiggle matching" method has been used. Wood samples with sufficient series of tree-rings (70-150 rings) from the barrows were subdivided into 10-20 tree-rings series which have been used for radiocarbon dating. The radiocarbon dates used are shown in **Table 1**. The agreement of the ^{14}C dates and tree-rings dates with the calibration curve was achieved with use of the statistical criterion χ^2, by minimising this criterion, taking into account the relative position of both the experimental points and the calibration curve and the statistical weight of each ^{14}C date. Well-preserved wood samples were collected from the following sites: Bashadar Barrow (Altai Mountains), Dogee-Baary-2 Barrows (Tuva), Cheremshino Barrow (Southern Siberia), and Berel Barrow (Kazakhstan). The latter two sites have not been previously dated. The positions of the radiocarbon determinations on the calibration curve and the reliable calendar age of the construction of the barrows are shown in **Figs. 2-5**. The final results are presented in **Table 2**.

The traditional estimate of time of the initial establishment of the Pazyryk Barrows as the 5th century BC (Zaitseva *et al*. 1997, Zaitseva *et al*. 1998) has been cast in doubt basing on the stylistic analysis of the art and funerary assemblage; the suggested age being the end of the 4th – the beginning of the 3rd centuries BC (Bunker 1991; Bunker *et al*. 1991; Kawami 1991; Lerner 1991 and Chugunov 1993). The latest results of radiocarbon dating of Pazyryk-2 Barrow establish the time of its construction as the beginning of the 3rd century BC (McCormac and Mallory 1999). Few radiocarbon determinations available for the Dogee-Baary-2 Tombs (Sementsov *et al*. 1998 and Görsdorf *et al*. 1998) suggest the time of their construction as the end of the 6th – the beginning of the 4th centuries

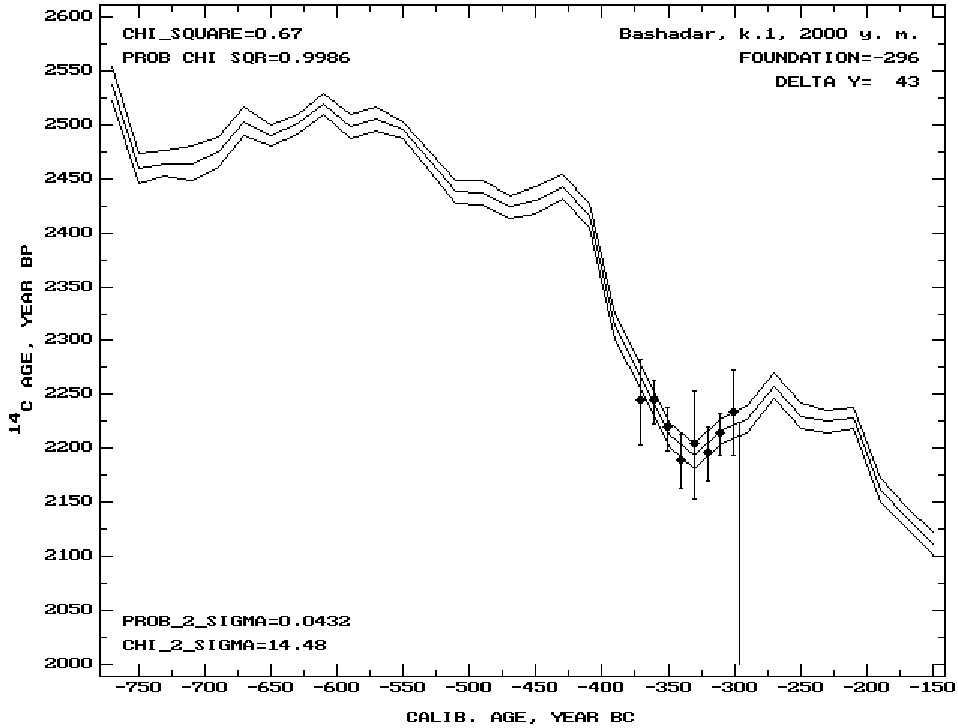

Fig.2. *The position of the radiocarbon dates for tree-rings series of the Bashadar Barrow (Mountain Altai region).*

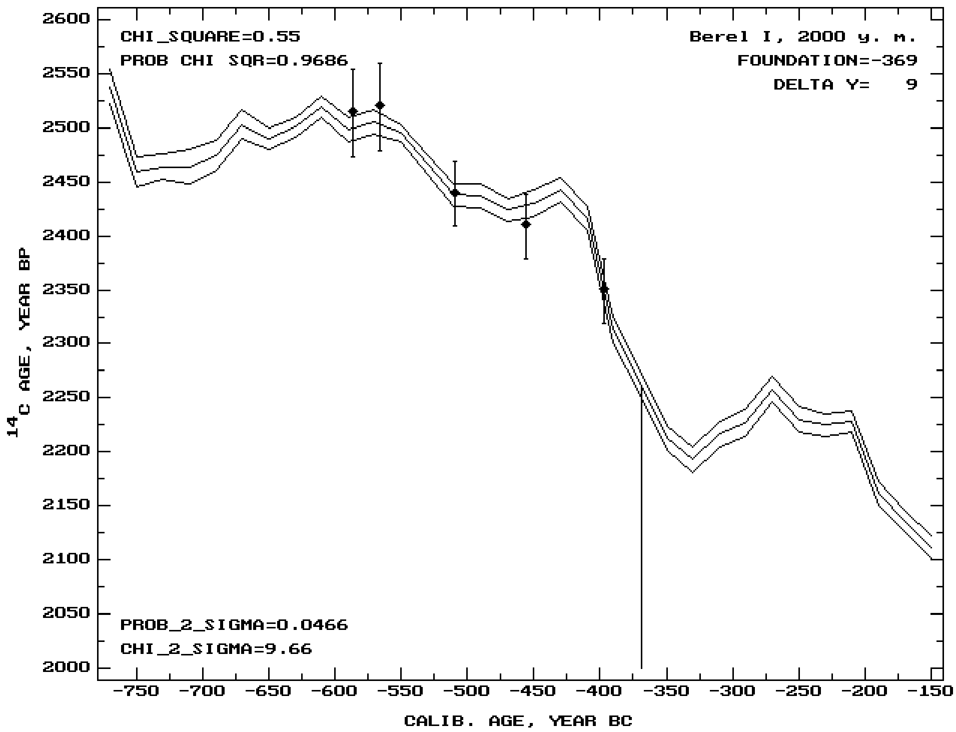

Fig.3. *The position of the radiocarbon dates for tree-rings series of the Berel Barrow (Kazakhstan).*

***Table 1.** Radiocarbon dates of wood samples used for the wiggle matching method.*

No.	Lab. index	^{14}C Age [BP]	Monument	Tree-rings position	Intervals of the calibrated age [BC] 1σ	2σ
			Altai			
1.	Le-5788	2200±40	Bashadar, barrow 1, 80 tree-rings	1-10 tree-rings	358-192	378-126
2.	Le-5789	2200±20	Bashadar barrow 1, 80 tree-rings	11-20 tree-rings	355-195	359-191
3.	Le-5790	2175±20	Bashadar barrow 1, 80 tree-rings	21-30 tree-rings	345-182	356-130
4.	Le-5791	2145±25	Bashadar barrow 1, 80 tree-rings	31-40 tree-rings	194-118	342-64
5.	Le-5792	2160±50	Bashadar barrow 1, 80 tree-rings	41-50 tree-rings	354-10	364-50
6.	Le-5793	2152±25	Bashadar barrow 1, 80 tree-rings	51-60 tree-rings	198-118	350-68
7.	Le-5794	2170±20	Bashadar barrow 1, 80 tree-rings	61-70 tree-rings	343-176	354-120
8.	Le-5795	2190±40	Bashadar-1, 80 tree-rings	71-80 tree-rings	358-184	372-116
9.	Le-5558	2250±30	Pazyryk-2, D 5, 128 tree-rings	41-60 tree-rings	376-208	386-202
10.	Le-5559	2140±25	Pazyryk-2, D 5, 128 tree-rings	61-80 tree-rings	192-116	200-60
11.	Le-5560	2150±30	Pazyryk-2, D 5, 128 tree-rings	81-100 tree-rings	198-114	352-56
12.	Le-5561	2220±25	Pazyryk-2, D 5, 128 tree-rings	101-120 tree-rings	360-202	366-196
13.	Le-5562	2270±25	Pazyryk-2, D 5, 128 tree-rings	0-20 tree-rings	388-254	392-206
14.	Le-5563	2375±25	Pazyryk-2, D 5, 128 tree-rings	21-40 tree-rings	472-392	512-388
15.	Le-5596	2310±40	Pazyryk-5, 100 tree-rings	18 central tree-rings	402-260	408-206
16.	Le-5597	2230±25	Pazyryk-5, 100 tree-rings	50 inside tree-rings	364-206	372-200
17.	Le-5598	2240±25	Pazyryk-5, 100 tree-rings	40 outside tree-rings	368-208	378-200
18.	Le-5742	2204±40	Pazyryk-5, 180 tree-rings	0-10 tree-rings	358-194	380-162
19.	Le-5743	2250±30	Pazyryk-5, 180 tree-rings	20-29 tree-rings	376-208	386-202
20.	Le-5744	2125±30	Pazyryk-5, 180 tree-rings	30-39 tree-rings	186-102	194-52
21.	Le-5745	2240±30	Pazyryk-5, 180 tree-rings	40-49 tree-rings	368-208	380-200
22.	Le-5746	2202±30	Pazyryk-5, 180 tree-rings	50-59 tree-rings	356-194	368-184
23.	Le-5747	2230±50	Pazyryk-5, 180 tree-rings	60-79 tree-rings	366-202	392-176
24.	Le-5748	2250±40	Pazyryk-5, 180 tree-rings	80-108 tree-rings	378-208	388-200
			Southern Siberia (Khakasia)			
25.	Le-5675	2700±50	Cheremshino, barrow 1, grave 1,	20 central rings	898-808	926-796
26.	Le-5676	2710±60	Cheremshino, barrow, grave 1	1st layer from the centre (~20 tree-rings)	900-812	990-796
27.	Le-5677	2540±40	Cheremshino, barrow, grave 1	2nd layer from the centre (~20 tree-rings)	794-552	802-526
28.	Le-5678	2400±20	Cheremshino, barrow, grave 1	3rd layer from the centre (~20 tree-rings)	484-401	516-399
29.	Le-5679	2370±20	Cheremshino, barrow,grave 1	4th layer from the centre (~20 tree-rings)	406-397	473-390
30.	Le-5680	2435±25	Cheremshino, barrow,grave 1	outside rings (~20 tree-rings)	746-410	756-404
			Central Asia (Tuva)			
31.	Le-5736	2498±30	Dogee-Baary-2, barrow 8, D-90230, 90 tree-rings	1-20 tree-rings	766-538	782-422
32.	Le-5737	2390±30	Dogee-Baary-2, barrow 8, D-90230, 90 tree-rings	21-30 tree-rings	508-396	752-390
33.	Le-5738	2380±30	Dogee-Baary-2, barrow 8, D-90230, 90 tree-rings	31-40 tree-rings	486-392	748-388
34.	Le-5739	2415±30	Dogee-Baary-2, barrow 8, D-90230, 90 tree-rings	41-50 tree-rings	516-404	754-398
35.	Le-5740	2395±40	Dogee-Baary-2, barrow 8, D-90230, 90 tree-rings	51-60 tree-rings	516-396	758-386
36.	Le-5741	2368±30	Dogee-Baary-2, barrow 8, D-90230, 90 tree-rings	61-80 tree-rings	474-390	516-384
37.	Le-5716	2459±30	Dogee-Baary-2, barrow 8, D-90234, 90 tree-rings	25-34 tree-rings	758-414	762-410
38.	Le-5717	2496±30	Dogee-Baary-2, barrow 8, D-90234, 90 tree-rings	35-44 tree-rings	764-536	780-420
39.	Le-5718	2462±30	Dogee-Baary-2, barrow 8, D-90234, 90 tree-rings	45-54 tree-rings	760-416	762-410
40.	Le-5719	2427±30	Dogee-Baary-2, barrow 8, D-90234, 90 tree-rings	41-50 tree-rings	744-406	758-400
			Kazakhstan			
41.	Le-5709	2340±30	Berel, barrow 11, grave 1 dendro-sample No. 90295, 228 tree-rings	171-228 tree-rings	402-386	472-266
42.	Le-5710	2400±30	Berel, barrow 11, grave 1 dendro-sample No. 90295, 228 tree-rings	111-170 tree-rings	510-407	752-394
43.	Le-5711	2430±30	Berel, barrow 11, grave 1 dendro-sample No. 90295, 228 tree-rings	66-110 tree rings	748-408	760-400
44.	Le-5712	2390±40	Berel, barrow 11, grave 1, dendro-sample No. 90295, 228 tree-rings	41-65 tree-rings	516-396	758-386
45.	Le-5713	2510±40	Berel, barrow 11, grave 1 dendro-sample No. 90295, 228 tree-rings	21-40 tree-rings	772-536	794-418
46.	Le-5714	2505±40	Berel, barrow 11, grave 1 dendro-sample No. 90295	20 central tree-rings	768-530	788-416

Table 2. *Chronology of the key sites based on the wiggle matching, tree-ring chronology and methods of mathematical statistics.*

Site	***¹⁴C Date [BC]***	***2σ error [years]***	***Correction to age [years]***	***Comments***
Bashadar	296	-20; +20	+43	Le- 5788 - Le- 5795
Berel	369	-30; +30	+9	Lå-5709- Le- 5714; Le- 5712
Cheremshino	723	-20; +20	+44	Le- 5675 – Le- 5680;
Dogee-Baary-2, barrow 8, dendrosample No. 90230	353	-10; +10	+40	Le- 5736- Le- 5741; Le-5736
Dogee-Baary-2, barrow 8, dendrosample No. 90234	367	-15; +15	-26	Le-5715 – Le-5719
Pazyryk-2.	288	-10; +10	+27	Le-5558-Le- 5563
Pazyryk-5.	262	-15; +10	-23	Le-5596-Le-5598
Pazyryk-5.	264	-15; +10	+3	Le-5742-Le-5748

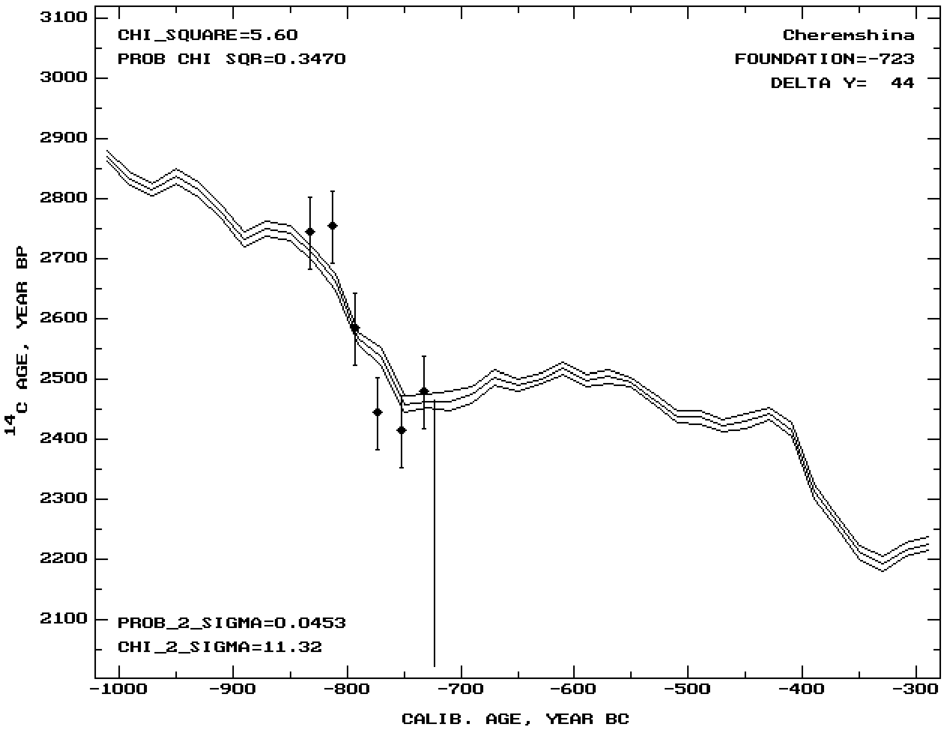

Fig.4. *The position of the radiocarbon dates for tree-rings series of the Cheremshino Barrow (Southern Siberia, Khakassia).*

BC. There is a good agreement between the dendro- and calendar ages based on ^{14}C determinations for the Dogee-Baary-2 and the Pazyryk-2 Barrows. According to the tree-ring chronology the Dogee-Baary-2 Barrow is older by 80 years than the Pazyryk-2. Similar ages were obtained with use of “wiggle-matching” method: 353-367 BC (Dogee-Baary-2) and 287-290 BC (Pazyryk-2). The Berel Barrow is older than Pazyryk-2 by about 80 years. Both the Bashadar and Pazyryk-2 have the same age. Significantly, Cheremshino has a similar age as the Arzhan Barrow. Until recently Arzhan has been considered to be the oldest Scythian monument in the entire Southern Siberia and Central Asia.

4. CONCLUSIONS

The comparative analysis of dating of the Scythian sites in Southern Siberia and Central Asia shows a good agreement between the cross-dating and radiocarbon results. The time of the construction of Barrow-8 of the Dogee-Baary-2 Tombs is estimated as the first third of the 4th century BC. For the first time the calendar age of the construction of the Cheremshino, Berel and Bashadar barrows has been identified. The age of the Cheremshino Barrow has been found to be similar to that of the Arzhan Barrow, both being the oldest Scythian monuments in Eurasia.

ACKNOWLEDGEMENTS

This research was supported by INTAS, project No 97-20362.

REFERENCES

Baillie M.G.L., 1982: *Sampling strategies.* In: *Climate from Tree-Rings*. Hughes M.K., Kelly P. M. and V. C. LaMarche Jr., eds, University Press Cambridge: 7.

Baillie M.G.L. and Pilcher, J.R., 1973: A sample crossdating program for tree-ring research. *Tree-Ring Bulletin* 33: 7-14.

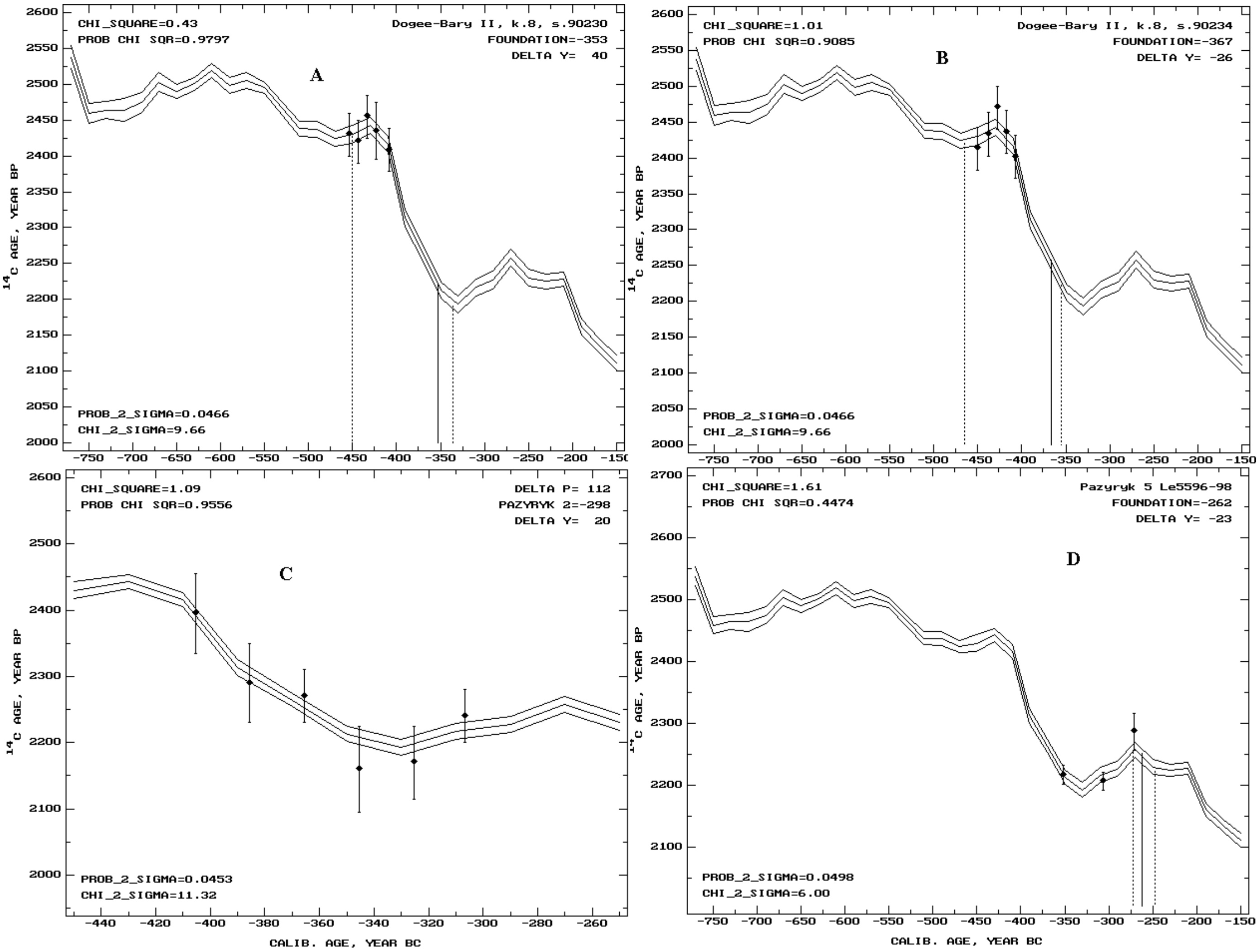

Fig.5. *The position of the radiocarbon dates for tree-rings series: A – the Dogee-Baary-2 Barrow, grave 8, Dendro-sample No. 90230; B – the Dogee-Baary-2 Barrow, grave 8, Dendro-sample No. 90234; C – the Pazyryk-2 Barrow; D- the Pazyryk-5 Barrow*

Bitvinskas T.T., 1974: Dendroclimatic Investigations (in Russian). Hydrometeoizdat, Leningrad.

Briffa K.R. and Jones P.D., 1990: Basic chronology statistics and assessment Methods of Dendrochronology. In: Cook E. and Kairiukstis L., eds, *Applications in the Environmental Science.* Kluver, Dordrecht: 137-152.

Bunker E.C., 1991: The Chinese artifacts among the Pazyryk finds. *Notes in the History of Art* 10: 20-24.

Bunker E.C., Juliano A., Kawami T. and Lerner J., 1991: Introduction. *Notes in the History of Art* 10: 4-6.

Chugunov K. V., 1993: The dating of the Great Pazyryk barrows: The new cycle of old discussion (In Russian). In: *Protection and study of the Cultural Heritage of the Mauntain Altai* 1: 167-169.

Deetz J. and Dethlefsen E., 1965: The Doppler Effect and archaeology: a consideration of the spatial aspects of seriation. *Southwestern Journal of Anthropology* 21(3): 196**.**

Dergachev V.A. and Vasiliev S.S., 2000: Cross-dating methods in dendrochronology and construction dates of Altai barrows. In: *Physics in Culture 1. The Solid State Physics in the Study of Cultural Heritage*: 217-223.

Eckstein D. and Bauch J., 1969: Beitrag zur Rationalisierung eines dendrochronologischen Verfahrens und zur Analyse seiner Aussagesicherheit. Forstwiss. *Centralbl.* 88: 230-250.

Fritts, **H.C., 1976:** *Tree Rings and Climate.* Academic Press, London

Fritts H.C. and Swetnam T.W., 1989: Dendroecology: A tool for evaluating variations in past and present forest environments. *Advances in Ecological Research* 19: 110-188.

Gorsdorf J., Parzinger H., Nagler A. and Leont'ev N., 1998: Neue ^{14}C–datierungen fur die Sibirische Steppe und ihre Konsequenzen fur die regionale Bronzezeitchronologie. *Eurasia Antiqua* 4: 73-80.

Kawami T.S., **1991**: Greek art and finds at Pazyryk. *Notes in the History of Art*10: 16-19.

Lerner J., 1991: Some so-called Achaemenid object from Pazyryk. *Notes in the History of Art* 10: 8-15.

Marple S.L., Jr, 1987: Digital Spectral Analysis with Applications. Prentice-Hall, New Jersey.

McCormac F.G., Reimer P.J., Mallory J.P. and Marsadolov L.S., 2000: The date of the Pazyryk tombs. In: *Proceeding of the 17th International Radiocarbon Conference. Radiocarbon* (in print).