^{14}C WIGGLE MATCHING OF THE 'FLOATING' TREE-RING CHRONOLOGY FROM THE ALTAI MOUNTAINS, SOUTHERN SIBERIA: THE ULANDRYK-4 CASE STUDY

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ABSTRACT. The Bayesian approach to calibration of radiocarbon dates was used to wiggle-match the "floating" tree-ring chronology from a Pazyryk culture (Scythian-type complex from Sayan-Altai Mountain system, southern Siberia) burial ground in order to estimate the calendar age of its construction. Seventeen bidecadal tree-ring samples were ^{14}C dated with high precision (±20–30 yr). The results of wiggle-matching show that the Pazyryk-type burial mounds in the southern Altai Mountains were created in the first part of 3rd century BC.

INTRODUCTION AND BACKGROUND

Site dating is one of the fundamental problems in archaeology of the Inner Asian Early Iron Age. The wide range of well-preserved wooden constructions from burial sites of early nomadic cultures in southern Siberia, and Inner Asia in general, allows the application of dendrochronological methods in age estimates. The tree-ring sequences from burials provide a good opportunity to obtain relative dates of their construction with very high precision (within the error of one year), which is not possible with any other dating method.

The Pazyryk culture of southern Siberia is widely known because of its large "tsar" burial mounds (*kurgans*), a unique phenomenon in the archaeology of Asia (cf., Khazanov 1984; Davis-Kimball et al. 1995). Because of ice formation inside the tombs, researchers were able to obtain materials of exceptional quality, including a rich variety of burial goods, mummified human bodies, and large wooden constructions of burial chambers and sarcophagi (Rudenko 1960).

Since the 1950s, several attempts were made to use dendrochronological methods for dating kurgans of early nomad sites in the Sayan-Altai Mountain system (Figure 1). It was concluded that the Pazyryk culture in the Altai Mountains in general and the Pazyryk, Bashadar, and Tuekta sites in particular, are dated to the 6th–2nd centuries BC. Zamotorin (1959) analyzed a collection of wooden stem discs from five large Pazyryk kurgans. Zakharieva (1974) analyzed wooden samples from the Pazyryk, Bashadar, and Tuekta sites. She established a 547-year long "floating" tree-ring chronological scale for the Sayan-Altai region, and incorporated into this scale an earlier burial mound of Arjan in the Tuva Republic. Marsadolov (1988) studied specimens from the Pazyryk site, burial mounds 1, 2, and 5, as well as from the Tuekta-1, Shibe, and Arjan sites. He established a "floating" tree-ring chronology of 634 years.

As mentioned above, the existing tree-ring chronologies represent relative or "floating" scales. Thus, the establishment of a calendar (i.e. "true") ages for the large kurgans of the Sayan-Altai Mountains is an important task. In the 1990s, ^{14}C dating was performed on the same wood samples that were used previously for the tree-ring analysis. Samples for ^{14}C dating, consisting of 15–40 tree rings, were taken from different wooden stem discs. Twenty-one ^{14}C dates were obtained for six

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burial mounds. The time period for the "floating" Sayan-Altai scale was established in the range of 900–400 BC, with an average error of 20–40 years (Marsadolov et al. 1996).

Construction of a 'Floating' Dendroscale for Southern Altai Archaeological Sites

In the 1970–1990s, archaeologists from the Institute of Archaeology and Ethnography, Siberian Branch of the Russian Academy of Sciences in Novosibirsk excavated the series of kurgans in the southern part of Altai Mountains (Figure 1) and associated them with the Pazyryk culture. Some of the tombs inside kurgans were frozen in ice (Kubarev 1987; Polosmak 1996). There are widely known tombs on the Ukok Plateau with female and male mummified bodies, such as tomb 1 of Ak-Alakha-3 burial ground, and tomb 3 of Upper-Kaldjin-2 burial ground (Polosmak 1996; Molodin 1995). The Pazyryk kurgans at the Ukok Plateau and in the Chuya River basin contain wooden constructions, including burial chambers, coffins, funeral beds, etc. Such diverse objects provide new material for tree-ring estimation of their relative age.

We based our research on a collection of 50 wood samples recovered from 12 kurgans corresponding to the Scythian period (Figure 1). They may be spatially grouped as follows: 1) burial mounds on the Ukok Plateau: kurgan 1 of the Ak Alakha-1 burial ground, kurgan 1 of the Ak Alakha-3 burial ground, kurgan at Kuturguntas site, kurgan 1 of the Upper-Kaldjin-1 burial ground, and kurgans 1–3 of the Upper-Kaldjin-2 burial ground; and 2) burial mounds in the Chuya steppe: kurgan 12 of the Ulandryk-1 burial ground, kurgan 1 of the Ulandryk-4 burial ground, kurgan 2 of the Tashanta-1 burial ground, kurgan 7 of the Yustyd-1 burial ground, and kurgan 18 of the Barburgazy-1 burial ground.

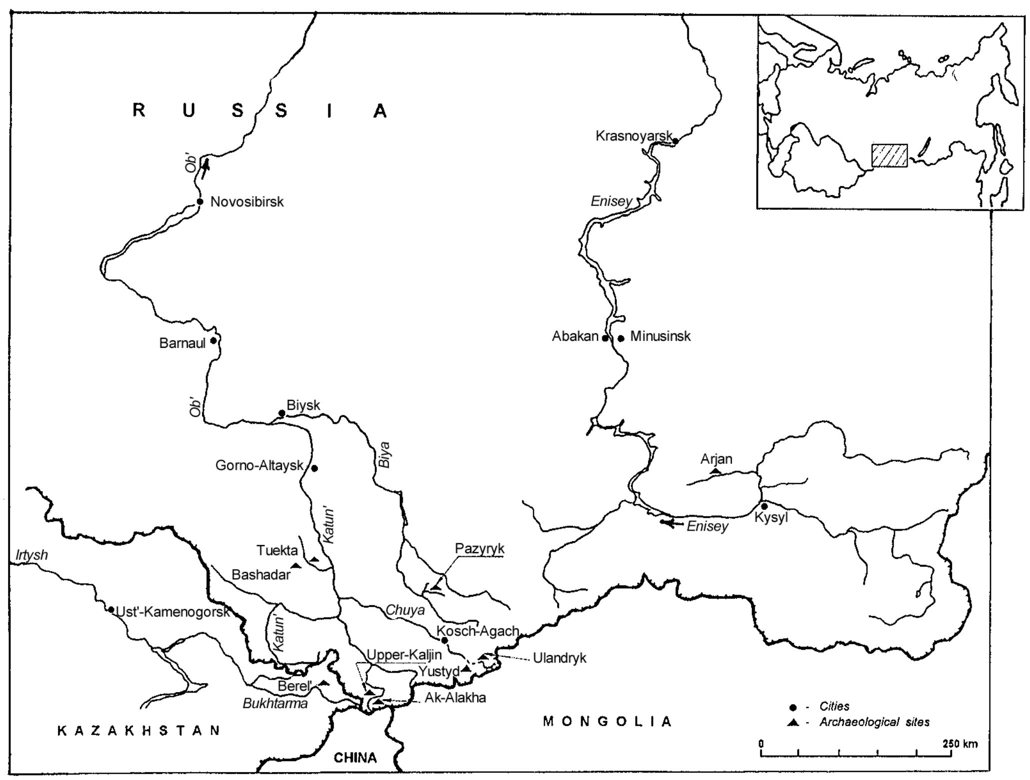

Figure 1 The location of sites mentioned in the text

These two groups are 250 km from each other at approximately at the same latitude (between 49°20′N and 49°40′N) and altitude (2000–2300 m above sea level) (Figure 1). Most of samples represent larch (*Larix sibirica* Pall.), though several samples of spruce (*Picea* sp.) were also obtained.

The analysis of wood samples and data synthesis has been performed in collaboration with the Laboratory for Dendrochronology of the Archaeological Bureau in Zurich (Switzerland). As a result, a "floating" tree-ring chronology was created (Seifert and Sljusarenko 1996). Since the kurgans at the Ukok Plateau are characterized by a series of samples, mean curves of annual tree-ring growth were constructed for each kurgan. The kurgans of the Chuya steppe yielded only a few samples of wood, which is why they all were pooled into a single mean tree-ring chronology. All the tree-ring growth curves demonstrate high similarity in the main characteristics. This allows synchronization of the curves within a single, generalized, 415-year-long "floating" tree-ring chronology (Seifert and Sljusarenko 1996).

The presence of the last annual tree ring in a majority of samples revealed the relative sequence of appearance of the kurgans in the southern Altai region. Unexpectedly, all kurgans but one were constructed during a short period of time of only 39 years. This time period corresponds to the interval between 376 and 415 years from the beginning of the relative chronology. Only one sample from kurgan 12 of the Ulandryk-1 burial ground has an earlier date of 287 years from the beginning of the "floating" chronology.

Wiggle-Matching Calibration of the 'Floating' Southern Altai Pazyryk Densdroscale

The tree-ring chronology for the southern Altai Mountains is a "floating" or relative one, i.e. it is not assigned a calendar age. Matching this scale with the calendar chronology is the key objective of this project. At present, it is impossible to create a dendrochronological scale for the region. The absence of both long-lived trees and long sequences of tree rings prevents filling the time gap of more than 1000 years between the "floating" scale and existing master chronologies for the Altai region (Panushkina and Ovchinnikov 2000). This is why we attempted to correlate the tree-ring scale with absolute age by means of ^{14}C dating, in particular with the help of the "wiggle-matching" method.

The reference specimen was chosen from kurgan 1 of the Ulandryk-4 site (49°42′N latitude; 89°08′E longitude; elevation ca. 2150 m asl) (Figure 1). This kurgan represents a stone barrow 13 m in diameter, under which a grave pit of 3.6 × 2.85 × 3.05 m was excavated. A rectangular burial chamber of larch logs was found at the bottom of the grave pit. The chamber, which contained a human skeleton, was filled with ice. Thus, all burial goods were well preserved. The grave goods include wooden- and earthenware, wooden decorative elements of a head gear and dress, a diadem carved in wood, elements of a warrior's belt, fragments of a bow and arrows, an iron dagger and battle ax, and fragments of fur and woollen cloth (Kubarev 1987:183–5).

The larch (*Larix sibirica*) sample (laboratory number 19116) was taken from a log from the chamber's wall. The diameter of the stem is 0.42 m; the number of annual rings is 363, and the last ring is preserved. Thirty-nine rings of sapwood are discernable. The whole range of annual tree rings occupies an interval between 26 and 388 years of the "floating" chronology of the southern Altai.

^{14}C dating of the wood was performed in 1999 at the ^{14}C laboratory of the Institute of Geology, Siberian Branch of the Russian Academy of Sciences in Novosibirsk. Standard liquid scintillation counting (LSC) equipment was used to measure ^{14}C age with high precision (±20–30 yr). The whole range of annual tree rings was subdivided into groups of 20 rings each. Seventeen samples, representing 340 rings (counted from the center), were selected for dating. Table 1 shows the ^{14}C dating results.

Table 1 List of ^{14}C dates of tree-rings from the Ulandryk-4, kurgan 1, Altai Mountains, southern Siberia

Tree-ring nr	Lab nr SOAN-	^{14}C date (BP)
1–20	4068	2528 ± 30
21–40	4069	2493 ± 20
41–60	4070	2468 ± 25
61–80	4071	2447 ± 20
81–100	4072	2432 ± 30
101–120	4073	2405 ± 25
121–140	4074	2387 ± 30
141–160	4075	2358 ± 25
161–180	4076	2335 ± 20
181–200	4077	2317 ± 25
201–220	4078	2280 ± 25
221–240	4079	2247 ± 25
241–260	4080	2217 ± 20
261–280	4081	2225 ± 25
281–300	4082	2210 ± 25
301–320	4083	2187 ± 20
321–340	4084	2180 ± 25

In this study, we apply the Bayesian approach to wiggle-matching of archaeological samples. The theory of wiggle-matching using Bayesian statistics is described in Christen and Litton (1995), based on the general framework for Bayesian calibration developed in Christen (1994) and Buck et al. (1996, chapter 9). Wiggle-matching refers to the simultaneous calibration of ^{14}C-dated samples of known deposition rate. In our case, we have ^{14}C-dated tree-ring samples where the elapsed time between the samples (number of rings) is known precisely.

One of the principal features of the Bayesian statistical approach is that it permits the incorporation of *a priori* information available about the problem at hand in a formal and coherent way. In the case of Bayesian calibration, the latter means that contextual *a priori* chronological information about dated material may be used to calibrate ^{14}C determinations onto the calendar scale. In particular for a tree-ring sequence, one uses the information of the number of years (tree rings) elapsed between samples to calibrate the ^{14}C results.

As described above, samples were taken from the larch log for every 20 rings. Assuming no missing rings, this means that the associated calendar year for each sample, say θ_j, should be 20 years older than the next sample, that is, $\theta_{j+1} = \theta_j + 20$ (using calendar years, or *cal BP*). Thus, starting with the outermost, latest sample, we have that θ_1, $\theta_2 = \theta_1 + 20$, $\theta_3 = \theta_1 + 40$, etc. This means that, by knowing θ_1, we know the calendar dates for all the samples.

On the basis of this, we build a model for the ^{14}C dating process and we generate a posterior distribution for θ_1. This distribution represents the probable years for θ_1, the mean calendar date for which the organic material in sample 1 ceased metabolizing; based upon all ^{14}C determinations obtained and the tree-ring chronology (see details in Christen and Litton 1995).

We used our software *Mexcal* to calculate the posterior distribution for the calendar dates of the outermost sample (θ_1). There are two alternative ways to produce the distribution, one including the errors in the calibration curve and another not including the errors (we used the internationally accepted 1998 calibration curve; see Stuver et al. 1998). We decided to primarily present the results obtained by the latter option. However, we will consider how these results compare with those obtained with the former.

The posterior distribution for θ_1 is presented in Figure 2. We see that there are three alternative peaks in the distribution; however, the middle one is noticeably higher than the others. This peak is at year 2190 cal BP, with a 16.9% probability of θ_1 being exactly that year. The next peak is at year 2197 cal BP (with 2.2% probability) and the smallest one is at 2179 cal BP (with 1.6% probability). Overall, the whole of the distribution for θ_1 is within the interval 2174–2203 cal BP, with a probability of more than 99%. The middle peak, covering 8 years from 2187–2194 cal BP is the shortest 77% highest posterior density (HPD) interval. We should notice that using the whole of the posterior distribution for θ_1 is far more complex, and precise assertions about the wiggle-match of the chronology may be given rather than simply stating a central year with an error (e.g. 2190 cal BP ± error).

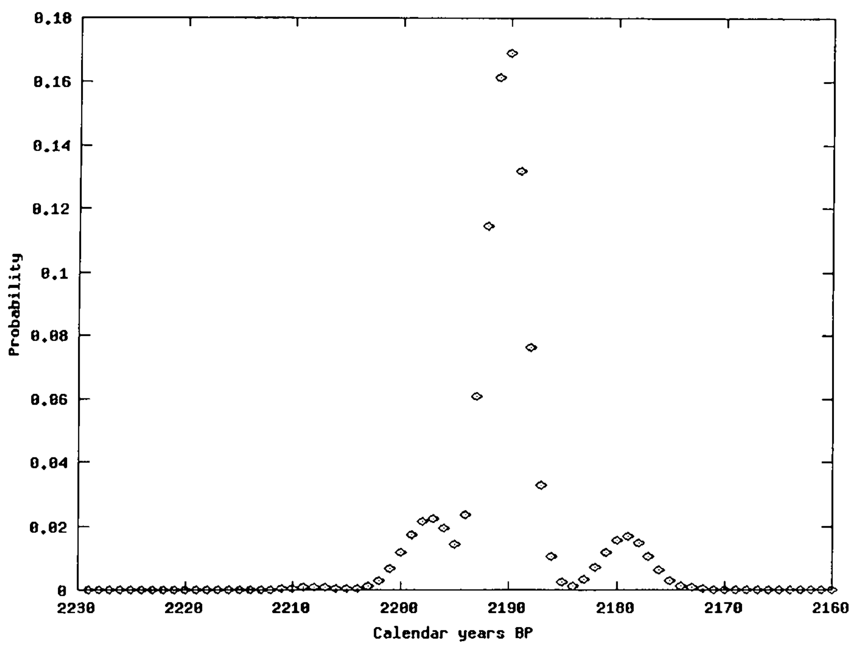

Figure 2 Posterior distribution for the latest sample from Ulandryk-4, kurgan 1; outermost rings (θ_1).

Including the errors in the calibration curve in the analysis (Christen and Litton 1995), the distribution for θ_1 covers the interval from 2169 to 2221 cal BP with a probability of more than 99%. New alternative peaks appear in this case and the probable years for the match are widened to some degree (see Figure 3). It is always the case that for this high-precision dating, differences appear depending on whether or not the errors in the calibration curve are considered (Christen 1994), thus highlighting the need for further research on this subject. In particular, the high peak in Figure 3 is merged with its neighbouring peaks leading into a far less probable match. In fact, the interval 2187–2194 cal BP has now only a 36% probability (and is no longer a HPD interval), and the highest peak

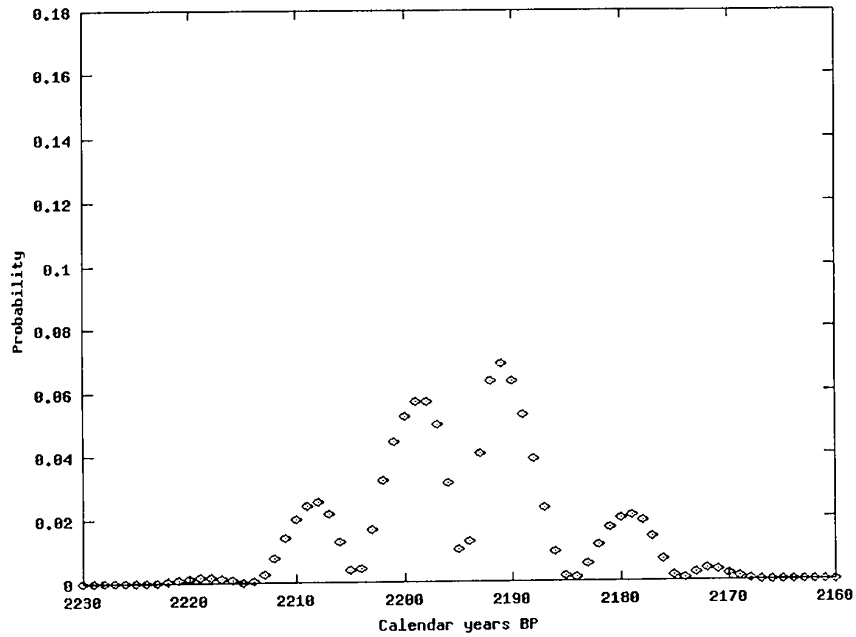

Figure 3 Posterior distribution for the latest sample of the Ulandryk-4, kurgan 1; outermost rings (θ_1), including the errors in the calibration curve.

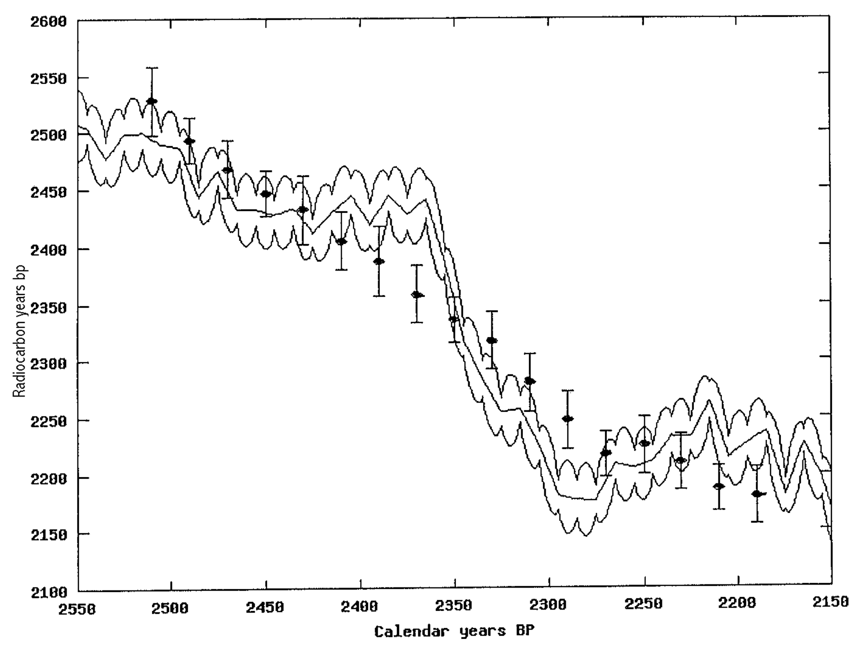

Figure 4 Illustration of the wiggle-match at 2190 cal BP; the estimated errors on the curve are also included (errors coincide with those quoted at the knots of the curve)

is now at 2191 years cal BP with a probability of only 6.8%. It is clear that this added uncertainty is a result of the uncertainty in the calibration curve.

Taking 2190 cal BP as our best "match", we present in Figure 4 the ^{14}C determinations with their standard errors as error bars, fixing the chronology at 2190 cal BP, and including the relevant part of the calibration curve. We have also plotted the estimated error of the curve (method explained in Christen and Litton 1995) as one standard deviation for every point on the piecewise linear curve. We should emphasize that all determinations fall within at most two standard errors from the curve.

CONCLUSION

This study represents one of the first attempts at Bayesian wiggle-matching the Pazyryk culture in Siberia. Assuming that the 340th tree ring of our "floating" chronology from kurgan 1 of the Ulandryk-4 site is dated to 2190 cal BP (i.e. 240 BC), the larch log used for the kurgan construction was cut down 23 years later, at the end of 3rd century BC (approximately at the year 217 BC). Thus, the time of creation of Pazyryk culture kurgans at the Ukok Plateau corresponds in general to the same time, approximately 230–190 BC.

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