PERIODICITY AS A BASIS FOR CROSS-DATING WOOD SAMPLES FROM HISTORICAL, RELIGIOUS AND CULTURAL REMAINS

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The problem of absolute datings based on wood samples from archaeological and historical monuments remains a complex one, with little in the way of reliable ^{14}C datings or historical sources to go on. Series of tree rings obtained from wood growing in similar environments and in the vicinity of ancient monuments therefore have great significance for dendrochronological research.

The main purpose of this article is to discuss from a methodological point of view the archaeological aspect of dendrochronology, and using illustrations demonstrate the practical realization of the technique. This has been done to trees from different areas, particularly from environments which differ markedly from the trees' natural growing areas. Special emphasis is placed on detection of the most pronounced rhythms typical of specific regions.

Researchers interested in tree ring growth, like Pokorny (1869), Shvedov (1892), Douglass (1919; 1928; 1936) and Beketov (1968), have demonstrated the vast possibilities offered by tree rings in obtaining valuable information in the fields of climatology, archaeology, heliophysics, forestry and others.

Zamotorin (1959; 1963), Zakharieva (1976), Marsadolov (1988; 1990; 1996) and several non-native researchers have dated the Sayan-Altai barrows from tree rings. However, disagreement between obtained absolute dates and archaeological hypotheses concerning sequences of construction of the barrows has introduced the use of a combination of different techniques to confirm or disprove the older datings. Still, new approaches are needed for cross-dating of wood samples from different kinds of historical, archaeological and religional monuments.

It is well known that the age of wood samples from archaeological sites can be obtained by radiocarbon dating. The relationship between calendar ages and measured radiocarbon dates is characterised by the calibration curve. High-precision radiocarbon data sets are available and calibration procedures are now widely used in the form of programs planned for personal computers (e.g. van der Plicht 1993). However, variations of radiocarbon content in the atmosphere in the past limit the precision of this method; this is visible in the highly irregular shape of the calibration curve. Large variations of radiocarbon content in tree rings known as "wiggles" show cyclicity with periods of about 210 and 2000 years (Dergachev and Chistyakov 1995).

The 210 year cycle in radiocarbon content over the last millennium can be correlated with the anomalous behaviour of the sun. Frequency analysis of radiocarbon data reveals the existence of a 210 year cycle with a statistical reliability of 0.9998 (Vasiliev and Dergachev 1995). These variations make conversion of radiocarbon ages into calendar dates more complicated, because one radiocarbon age can correspond to more than one calendar date. Even a 2000 year long period in the variation of radiocarbon content in the atmosphere can be observed. The variations can be seen as plateaux in the calibration curve. In order to correct radiocarbon measurements for such ambiguities, it is necessary to have calibration data for the same time interval. Certainly, tree ring records of known ages are ideal material for more accurate radiocarbon calibration.

It appears that medium-term and long-term wiggles revealed in the radiocarbon calibration curve can be used for matching floating chronologies from different parts of the world and in such a way as to extend the calibration curves. In recent years wiggle matching has been used to match not only floating tree ring chronologies but also organic deposits from peat bogs (van Geel and Mook 1989). Van der Plicht (1996) has demonstrated that wiggle matching of peat deposits increases dating accuracy significantly.

Because the 210 year wiggles in radiocarbon content correspond to variations in solar activity and the 2000 year wiggles coincide with reduced solar activity and alternating climatic cycles (Dergachev and Chistyakov 1995), it is interesting to compare these with variations in tree ring growth–especially since tree rings give absolute dates between the events studied.

Many years' experience in studying the radial growth of living tree species (Lovelius et al. 1966–1996) from different geographical zones allows us to trace the presence of polyrhythmics in annual ring growth and follow their spatial distribution. It could be established that rhythms with longer periods can be observed over large territories (Lovelius 1979).

Dendrograms of the radial growth of trees (Fig. 1) in the northern limit of the forest zone in Eurasia (1), in the northern limit in Alaska (2), and in the marshy forests

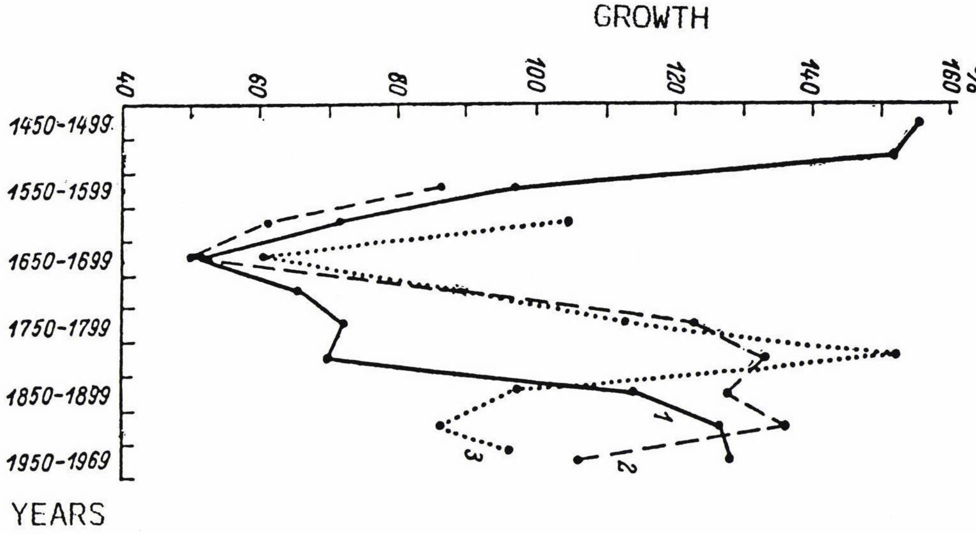


Fig. 1. Changes of the radial growth of trees: (1) in the northern limit of the forest zone in Eurasia (Lovelius 1979), (2) in the upper forest boundary in Alaska (Karlstrom 1966), and (3) in the marshy forests of Western Siberia (Glebova and Pogodin 1972). The data has been given as deviations from a 50 year sliding mean.

of Western Siberia (3) confirm the uniformity of the reaction of wood plants in a large in the northern hemisphere if natural conditions change. One might suggest that the main variation seen in the figure is the reaction of trees to changes in solar activity during the Maunder Minimum (AD 1645–1715). The clear minimum in tree ring growth on two continents during this period has been noted earlier by Lovelius (1979).

The most widespread rhythms are known to cover periods of 120–130, 60–65, 24 and 12 years (Lovelius 1970; 1979). They have been determined by the following analyses: a) the "sliding" mean, which evens out the wiggles of the curve, b) construction of integral-differential curves, c) the method of imposed periods in relation to variations of solar activity over 11 and 22 year cycles, d) the combination of imposed periods with the following integration, and e) Fourier analysis.

It should be noted that the definition of a 120–130 year long period is to a certain extent hypothetical, as its replication in the series studied is not sufficiently well established on the level of statistical significance. For the same time, rhythms of 120–130 and 60–65 years have been traced only in data series of Larix wood tree rings from the central part of the forest zone in the area of the Tunguska catastrophe and in the region of Bratsk city. Figure 2 shows an example of the latter. It can be seen that 11, 21 or 31 year smoothing does not change the pattern of the rhythms.

Figure 3 shows the results of the analysis of changes in Larix annual ring width in the growth limit area in the Suntar-Khayata mountains during the past 400 years (Lovelius 1979).This figure distinctly demonstrates rhythms of about 160 and 65 years. Our opinion is that the determination and application of rhythmical components in the dating of sites extends the range of use of annual ring series, while there is no alternative in cases where reference points are lacking or are poorly manifested in the growth of analysed woods.

The 11 year period is distinctly traced in the semi-arid conditions of the Ukraine steppe forests and in the central part of the Russian Plain (Lovelius, Belgard and Gritsan 1992). It has been confirmed that increased growth of tree rings coincides with periods of solar maxima, and reduced growth with periods of solar minima. Observations of pine growth during periods of anomalous solar activity support these determinations.

Variations in the growth of *Pinus Aristata* in the forests of South-Eastern Ukraine are in good accordance with anomalies in solar activity which have also been traced in the central part of the Russian Plain (Taranov and Lazarenko 1990). This indicates the stability of such rhythmic changes over large areas where conditions for tree growth are the same.

The 11 and 22 year periods have been studied in different regions of our planet. Lovelius (1995) detected significant differences in the amplitude of variations in growth of coniferous trees in three regions in Mongolia which coincide with the 11 and 22 year cycles in solar activity. Similar trends have been observed in the growth of *Pistacia vera* in Badhyz (Lovelius and Rodin 1990). However, ring growth during the 11 year maxima in solar activity has increased in trees in Badkhyz, while it has decreased in trees from Mongolia.

Great amplitudes over a 22 year period have been traced particularly clearly in the growth of *Pistacia vera.* At the same time, the occurrence of the 11 year cycle is not always pronounced. For example, the 11 year cycle is poorly traced in the ring width data of *Chosenia arbutifolia* from Kamchatka (Lovelius 1992), whereas an entirely different picture emerges for the 22 year cycle. The 22 year cycle in the growth of *Chosenia arbutifola* has been confirmed by different methods such as dendrograms based on integrals of the radial growth and by Fourier analysis.

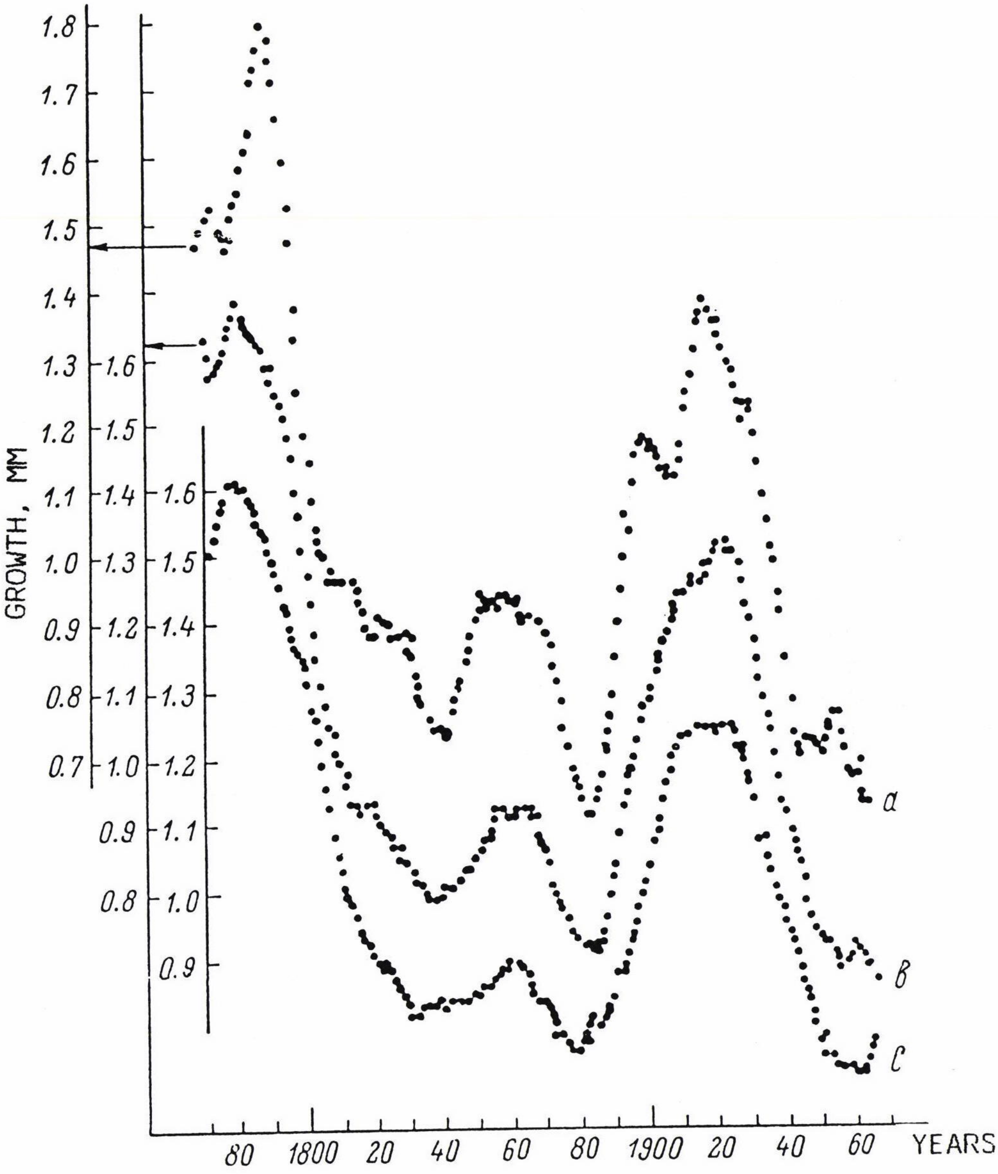
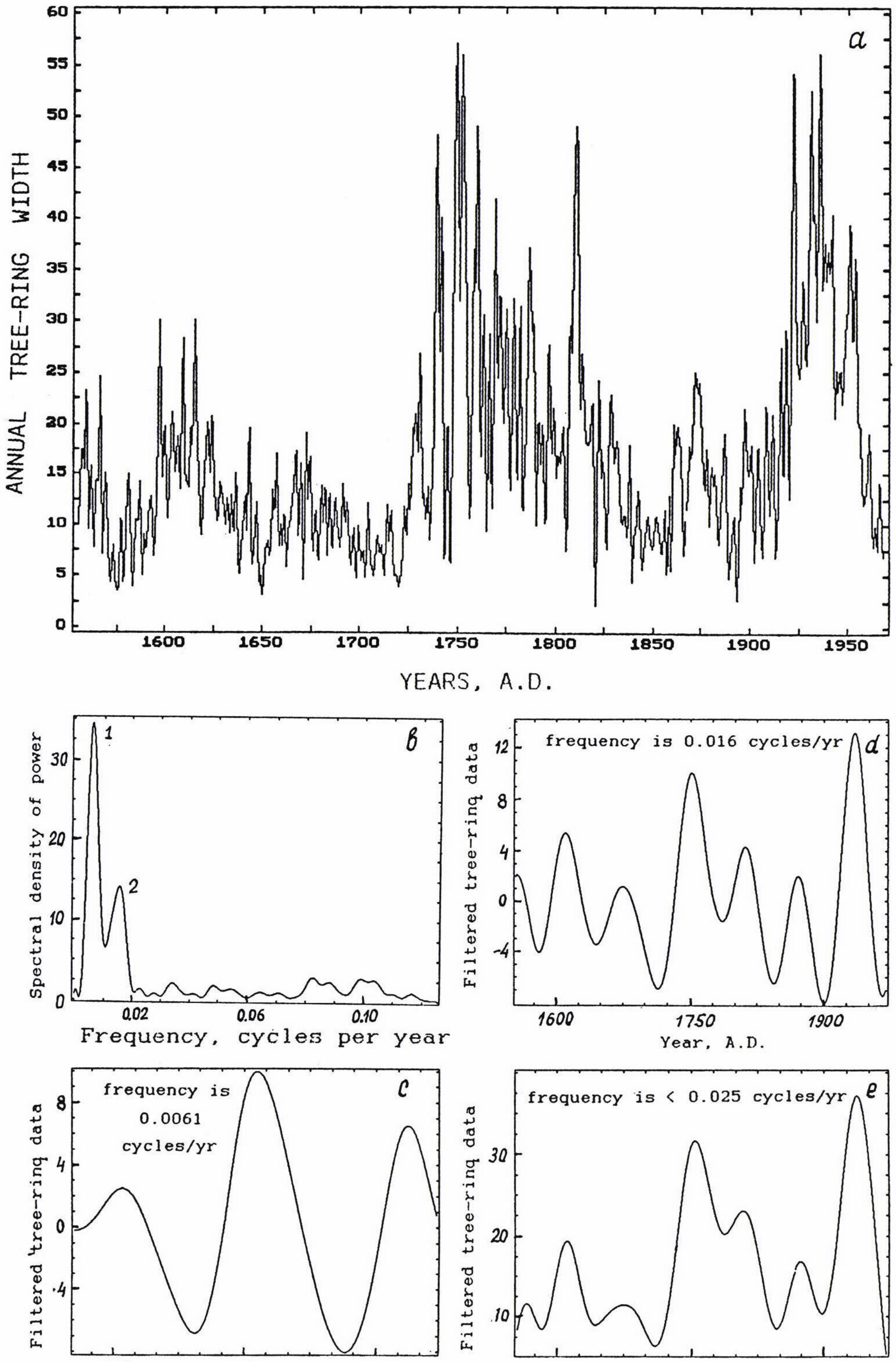


Fig. 2. Dendrograms of annual rings of Larix wood from test places located in the region of Bratsk city. Using (a) 11, (b) 21, and (c) 31 year sliding means.

Fig. 3. Dendrograms and results from calculations of power spectral density of 400 year series of annual ring widths of Larix wood from the upper growth limit of forest in the Suntar-Khayata mountains (Lovelius 1979).

a) The thickness of annual rings in 0,1 mm.
b) Relative power spectral density of the series. The peak maxima correspond to the frequencies:
  1 – 0.0061 cycles per year (the period is about 163 years),
  2 – 0.016 cycles per year (the period is about 64 years).
c) The result from filtering the data in the vicinity of frequency of 0.0061 cycles per year.
d) The result from filtering the data in the vicinity of frequency of 0.016 cycles per year.
e) The result after filtering with a low frequency filter accepting frequencies below 0.025 cycles per year (corresponding to a period of about 40 years).


a
ANNUAL TREE-RING WIDTH
0
5
10
15
20
25
30
35
40
45
50
55
60
1600
1650
1700
1750
1800
1850
1900
1950
YEARS, A.D.
в
1
2
Spectral density of power
0
10
20
30
0.02
0.06
0.10
Frequency, cycles per year
d
frequency is 0.016 cycles/yr
Filtered tree-ring data
-4
0
4
8
12
1600
1750
1900
Year, A.D.
c
frequency is 0.0061 cycles/yr
Filtered tree-ring data
-4
0
4
8
1600
1750
1900
Year, A.D.
e
frequency is < 0.025 cycles/yr
Filtered tree-ring data
10
20
30
1600
1750
1900
Year, A.D.

Analysis of annual ring series of coniferous trees from 10 mountain regions in the growth limit areas in Eurasia (Lovelius 1970) shows that rhythms of 12 and 24 years (Fig. 4) are most typical for the upper forest boundary. The 24 year rhythm has a significantly larger amplitude than the 12 year cycle. During periods of maximum solar activity the growth of trees in the upper forest boundary decreases and during periods of minimum activity increases, in such a way that extreme growth in both cases has been observed 2 years after the dates of anomalies in solar activity.

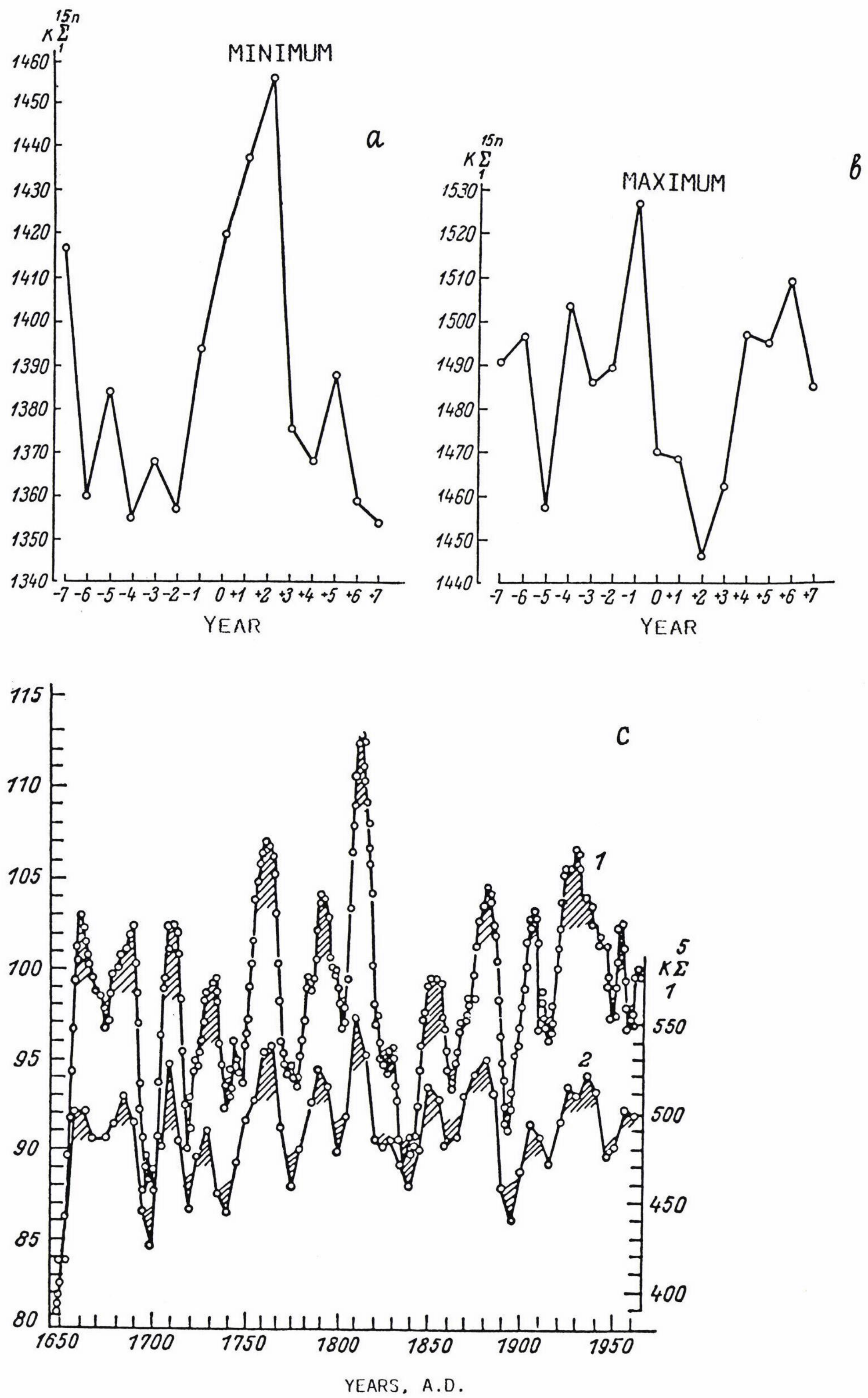
Analysis of the influence of solar activity on tree ring growth has shown that the spread of coniferous species in Northern limit areas is directly proportional and in the Southern limit areas inversely proportional to solar activity (Lovelius 1970; 1979; 1995). Maximal deterioration of conditions of the forest in the Northern limit occurred around 1840 AD, and a transition to extreme improvement of conditions can be found around 1550 AD. Such results show that anomalous radiocarbon dates are a consequence of anomalies in solar activity over certain periods.

The correlation of radiocarbon dates and floating tree ring series makes it possible to date more reliably the wood found in the context of various kinds of historical, religious and cultural relics, provided the rhythmic components are taken into account. Figure 5 shows an example of such a construction. As can be seen in the figure, a combination of radiocarbon dates and dendrochronological tree ring series makes it possible to date the barrows (Arzhan, Tuekta–1, Pazyryk–2, Pasyryk–5).

The main tasks of our investigations are the following: to create standard tree ring series for the regions in Eurasia, using territorial analogies in ring width data to reveal the basic parameters of prevailing periodicity, as well as to combine radiocarbon and dendrochronological time scales for different historical periods and regions of the world. At the same time, this approach allows us to carry out the reconstruction of palaeoclimatic conditions for periods for which data from instrumental observations are lacking. Attention is focused especially on the search for series of annual tree rings for regions with natural conditions similar to those prevailing at the locations of elite barrows on the Eurasia steppes.

Why are we studying history? The answer is evident: in order to understand the present. For that reason, investigations in the humanities must be as precise as in any field of science.

Fig. 4. The ring widths of coniferous trees from the upper limit of forest zones in10 mountain regions in Eurasia (Lovelius 1970) over periods of minimum (a) and maximum (b) of the 11–year solar cycle. c) A generalized dendrogram of the growth indices for the annual rings of coniferous trees from these regions: (1) 31 year sliding mean, 2) the pentad procedure followed by smoothing of the weighted mean.


a
MINIMUM
$K\Sigma_1^{15n}$
1460
1450
1440
1430
1420
1410
1400
1390
1380
1370
1360
1350
1340
-7 -6 -5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5 +6 +7
YEAR
b
MAXIMUM
$K\Sigma_1^{15n}$
1530
1520
1510
1500
1490
1480
1470
1460
1450
1440
-7 -6 -5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5 +6 +7
YEAR
c
115
110
105
100
95
90
85
80
1
2
$K\Sigma_1^5$
550
500
450
400
1650
1700
1750
1800
1850
1900
1950
YEARS, A.D.

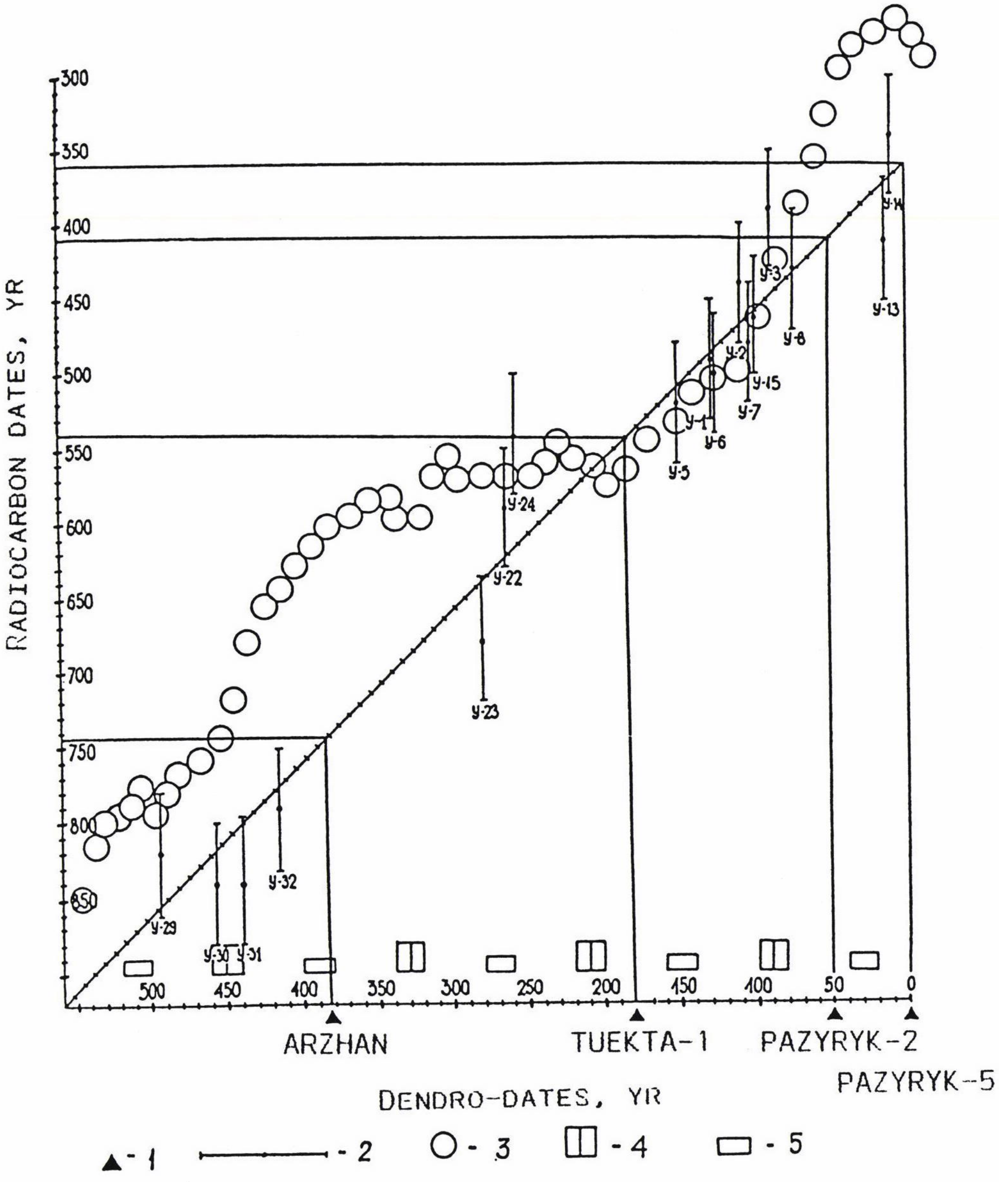


Fig. 5. The determination of time of construction of barrows at Sayan-Altai from the 1st millennium BC using radiocarbon and dendrochronological data.

1 – the date of construction of barrow

2 – the radiocarbon date for Sayan-Altai samples.

3– radiocarbon dates from American researches,

4 – the 120-year period for wood samples of Sayan-Altai,

5 – the 60-year period for wood samples of Sayan-Altai.

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