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A New Approach to the Study of Archaeological Charcoal: The Case of Metallurgical Furnaces of the Southeastern Altai

In recent years, dendrochronological analysis in archaeology has undergone a substantial transformation, offering an opportunity to use samples of wood that were previously considered uninformative. One striking example is the analysis of charcoal excavated from archaeological sites. We have studied 448 samples of charcoal collected from metallurgical (iron smelting) furnaces in the Kurai and Chuya basins of the Russian Altai Mountains. Earlier methods of preparing such samples were slow and inefficient. Our approach guarantees fast, simple, and high-quality preparation of a large number of samples of virtually any size and shape. Its advantages include low cost of apparatus, high quality measurement of annual rings, the possibility of efficient remote measurement, no need for verification, and a wider range of measured parameters of the annual ring. Hopefully, the new approach will help to solve the critical problem relating to the construction of a tree-ring chronology in the arid zone of Southern Siberia. Such a chronology will be highly prospective for assessing the age of wood from numerous mounds in the intermountain depressions of the Altai-Sayan region, and year-by-year reconstructions of the humidity regime; and for revealing extreme droughts and other climatic phenomena in this territory.

Keywords: *Dendrochronology, archaeology, anthracology, charcoals, metallurgical furnaces, Altai Mountains.*

Introduction

The rapid development of science and technology in the 20th century has generated a wide range of new methods used in studying objects of material culture. Applications of methods from natural sciences have been so successful that they have entered the standard practices of archaeological research. One of these methods is dendrochronology, which is widely used in analyzing the finds of well-preserved wood (Myglan et al., 2020; Zharnikov et al., 2020; Büntgen, 2019). As a result, a separate field of dendrochronological research (dendroarchaeology) has emerged both abroad and in Russia (Hollstein, 1984: 21; Karpukhin, 2016: 52). In recent years, this field has been undergoing substantial transformation from the introduction into practical research of non-invasive methods for studying wood (Domínguez-Delmás, 2020). Furthermore, original data have been digitized, marking a shift from direct measurement of annual-ring width on wood samples to simultaneous measurement of multiple parameters on digital images obtained using various types of scanners, cameras, microscopes, and other similar equipment. For example, the new approach has made it possible to establish the age of boards for Old Russian icons of the 15th–17th centuries (Matskovsky, Dolgikh, Voronin, 2016), and the "blue intensity" method of analyzing annual-ring density was used in dating wooden structures in the town of Yeniseisk (Myglan et al., 2018).

New approaches offer the opportunity to employ the evidence that previously was not considered to have had great scholarly value because of the technical impossibility of extracting all the information from it. One vivid example is charcoal. The special field of anthracology focuses on studying this type of material evidence (Scheel-Ybert et al., 2003). Charcoal is very common and has often been discovered during archaeological excavations. Yet, until now it has been considered suitable only for establishing species and radiocarbon dates (Filatova, Filatov, 2021), but unpromising in terms of dendrochronology. As a result, the capacity of charcoal—an important source of information about the past—remained underused.

This article demonstrates the effectiveness of a new method of preparing charcoal samples from archaeological sites, which removes the former limitations on using dendrochronological approaches. The results of the study clearly show that charcoal is currently one of the most underestimated and yet highly promising sources of information about the past.

Material and methods

The collection of charcoal analyzed in this study was gathered at archaeological sites in the Chuya and Kurai basins in the mountains of the Russian Altai (Fig. 1). The system of these depressions, separated by the Chagan-Uzun mountain group, extends for 120 km in the sublatitudinal direction. This area has a sharply continental cold climate with high annual and daily temperature ranges, a short frost-free period, a small amount of snow in the winter, and a general lack of precipitation. According to the Kosh-Agach meteorological station, located in the Chuya basin, the average annual temperature there is below 0°C, and in 1981–2010 it was –4.2°C. The annual amount of precipitation is 80–150 mm in the Chuya basin and 150–200 mm in the Kurai basin; about two-thirds of the precipitation occurs in the summer.

Fig. 1. Location of sites for sampling charcoal (*a*) and wood for the construction of tree-ring chronologies Kur and Jelo (*b*).
1 – Kuekhtonar; 2 – Yustyd; 3 – Kur for the forest-steppe zone, 4 – Jelo for the upper forest boundary.

The Chuya basin is the largest in the Altai. It reaches 70 km in length and 40 km in width, narrowing to 12 km in the eastern part. Its slightly concave bottom drops from 2100 to 1730 m above sea level in the northwestern direction. The central part of the basin is located at absolute heights of 1750–1850 m and is constituted mainly of semi-deserts with salt- and drought-resistant vegetation. Poplars and willows grow in the floodplains of rivers; occasionally, there are single trees of Siberian larch. The larch's somewhat wider occurrence in the recent past is indicated by the remains of larch-stumps in the floodplain near the village of Kosh-Agach. Small larch forests sometimes appear in the Chuya depression on the slopes of the northern and northwestern exposure.

The Kurai basin, measuring 25 km in length and 20 km in width, slopes generally towards the northwest, and sits at an altitude of 1500–1600 m above sea level. While the southeastern part of the basin is flat, the surrounding ridges give way to deserted steppes. In the northwestern part of the depression, a rocky foundation forms a hilly plain predominantly covered by dry steppe. Ribbon forests and groups of Siberian larch grow in hollows of the terrain. On the southern slope, a continuous belt of spruce, Siberian pine, and larch forest stretches, with an upper boundary at around 2350 m above sea level, further to the east, to the Chuya River valley. On the northern slope, the forest is sparse owing to greater solar exposure and aridity, has an insular distribution, and consists mainly of larch.

The arid climate and small population have contributed to the good preservation of a huge number of archaeological sites from the Late Paleolithic to the Middle Ages in the area (Derevianko, Markin, 1987; Kubarev, 1991; and others). These sites include iron-smelting furnaces, the abundance of which has made it possible to identify the Chuya-Kurai metallurgical region of the Russian Altai (Zinyakov, 1988: 31).

Collections of samples in the form of slags with high content of charcoal, and individual charcoals, were collected by A.R. Agatova and R.K. Nepop in archaeological excavations of metallurgical furnaces in the Kurai and Chuya basins, and in the valley of the Chuya River between them (Fig. 2). Initially, the samples were taken for establishing the age of the sites by radiocarbon dating, the upper chronological boundary when terraces with archaeological sites emerged, and for calculating slope-retreat rate (Agatova, Nepop, Korsakov, 2017; Agatova, Nepop, Slyusarenko, 2017; Agatova et al., 2018). However, good preservation of charcoals and large number of well-discernable tree rings even in small fragments suggested the idea of using the dendrochronological method for their dating. In the eastern part of the Chuya basin, in the valley of the Yustyt River, samples were collected over a number of years at the site of excavations carried out by N.M. Zinyakov in 1978 (1988: 38–42). Pieces of slag reaching 40–50 cm in size, with numerous inclusions of charcoals, lay either directly in the hollows, which emerged from excavated furnaces along the edge of the lower left-bank terrace, or at the foot of its slope. For this reason, attribution of charcoals collected at the Yustyd site with furnaces No. 2 (samples marked u2), 3 (u3), and 5 (u5) was rather conventional. Despite the fact that slags with fragments of charcoal lay on the daytime surface for over 35–40 years, their degree of preservation was satisfactory for dendrochronological research. At the mouth of the Kuektanar River (in the valley of the Chuya River, between the Chuya and Kurai basins), the samples were originally (in 2014) taken from pieces of slag scattered on the terrace after the excavations by N.M. Zinyakov at the Kuekhtonar-2 site in 1976 (Ibid.: 48). Later (in 2020 and 2021), the samples were taken from the spoil heap remaining from excavations by E.V. Vodyasov in 2019 (Vodyasov et al., 2020). Samples from 2020 were marked with letter “k”; samples from 2021 with letters “kk”. In total, the collection included 12 pieces of slag (from 10 to 40 cm in size) and individual pieces of charcoal.

For assessing the dendrochronological capacity of the collection, small pieces of charcoal reaching 20 mm in diameter were selected in a laboratory. The transverse fractures made revealed that these pieces contained 50 or more growth rings. Since the collection contained a significant number of larger charcoals, it had great capacity for constructing an extended tree-ring chronology. However, the fundamental point related to the choice of effective method for sample preparation, which would produce high-quality images, had still remained unresolved.

The analysis of the available approaches revealed their low efficiency in terms of fast processing of the collection of charcoals (in Russia, there were no studies on constructing a tree-ring chronology from charcoals). We should briefly discuss them. The classic method involves breaking charcoal in the transverse direction. While annual rings would become visible on the broken surface, there would be no external dirt traces. However,

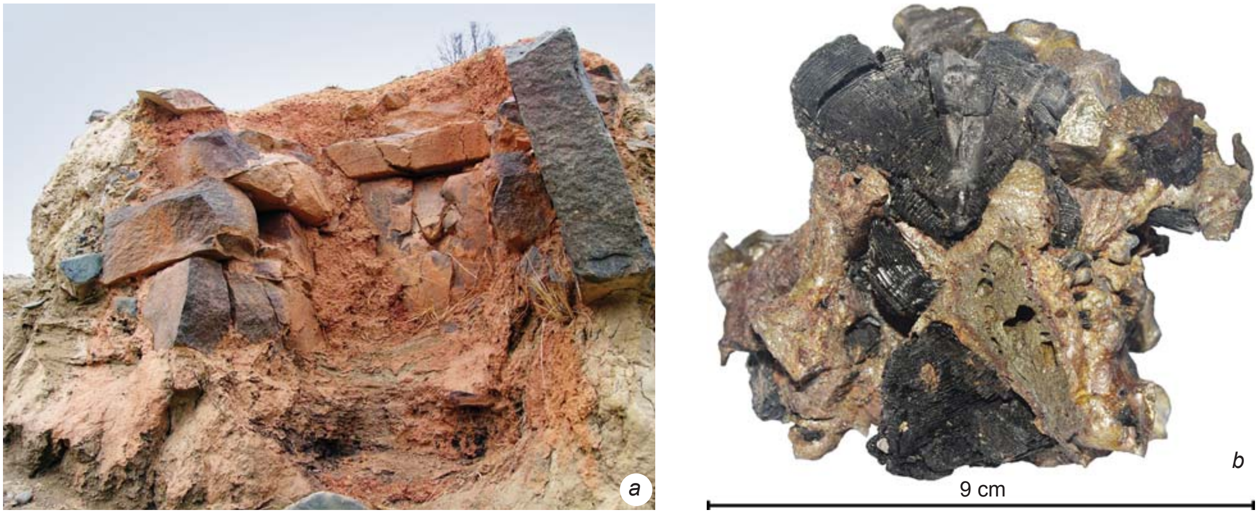

Fig. 2. External view of an iron-smelting furnace at Kuekhtonar-1 (*a*) and slag with fragments of charcoal from Kuekhtonar-2 (*b*).

in our case, breaking large charcoals (over 50 mm in diameter) was difficult, and small charcoals (up to 8 mm) often became destroyed from mechanical impact. The main disadvantages of this approach were inability to obtain consistently a flat plane along the breakage, and loss of the sample in the case of failure. Despite good end-results, the method of manual trimming of charcoal surface by a blade under microscope and contrast enhancement (with chalk powder, paste, or other finely dispersed compositions) was poorly applicable for mass processing, as it required significant labor costs and highly qualified personnel. The option of impregnating charcoals with complex compounds and subsequent trimming (polishing) allowed for an excellent quality image to be obtained. However, the high cost of equipment and consumables for sample preparation made this method unsuitable for mass processing.

In order to solve this problem, the team from the Siberian Dendrochronological Laboratory elaborated a method that facilitates fast and high-quality sample preparation of a large number of charcoals of any size and shape with minimal labor costs. Notably, the method relies on standard (conventional) grinding and microscopic equipment available in almost every natural science laboratory studying wood. This method has high accessibility (reproducibility) without any additional financial costs of purchasing specialized equipment.

The samples arrived at the laboratory both as individual charcoals and as pieces of slag with inclusions of unburned charcoal fragments (Fig. 2, *b*) that had to be extracted with the least possible loss. For achieving this, large fragments of slag with high content of charcoal were separated using a pick; in some cases, an angle grinder with a diamond disc was used. A total of 448 samples were prepared. They were processed on a disc-belt grinder (belt P600, 1000, wheel P1000). Charcoal dust, which fills the tracheids and prevents visualization of the cellular structure, is accumulated in the process of polishing the samples. An industrial vacuum cleaner was used for removing dust. It is very important to pre-dry the charcoals (to a level of no more than 7 % moisture), since with excessive moisture, the dust clogs the tracheids, sticks together, hardens when dried, and can no longer be removed.

The prepared charcoal pieces (Fig. 3) were photographed in reflected light at ×30 magnification, using a Zeiss AXIO Zoom V16 microscope equipped with a motorized object table. The photographs of the growth rings in the samples were stitched together in the ZEN (Carl Zeiss) software package, supplemented with the accompanying information on magnification, scale, etc., and then converted to the TIFF (Tagged Image File Format) format. Subsequently, the images were processed using the CooRecorder 9.3 (CR) software (Larsson, 2013), where linear parameters, such as the width of the annual ring, early and late wood, were measured manually (Fig. 3, *b*). The data were visually represented using the CDendro 9.3 software (Ibid.). All measured series were dated with a combination of graphical cross-dating (Douglass, 1919) and cross-correlation analysis using the DPL (Holmes, 1984) and TSAP V3.5 (Rinn, 1996) specialized software packages

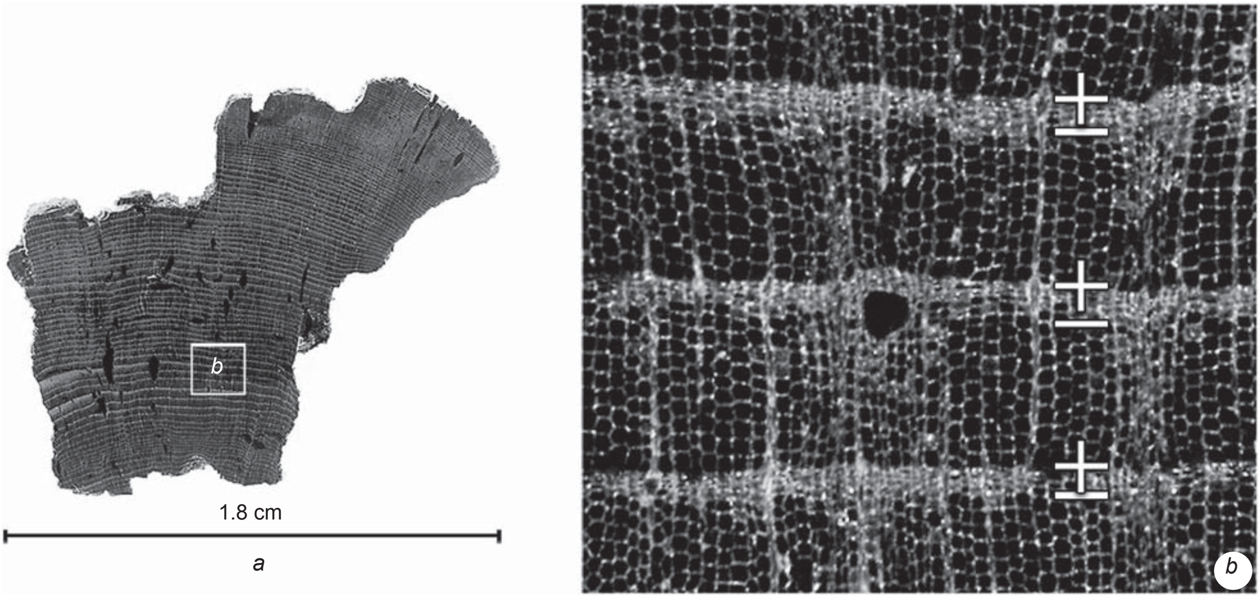

Fig. 3. Example of the sample k18 preparation.
a – general view and size of the sample containing 107 growth rings; *b* – prepared charcoal surface for measuring linear parameters of the annual ring. Crosses mark the boundaries of growth rings; horizontal dashes mark the boundary between the early and late wood.

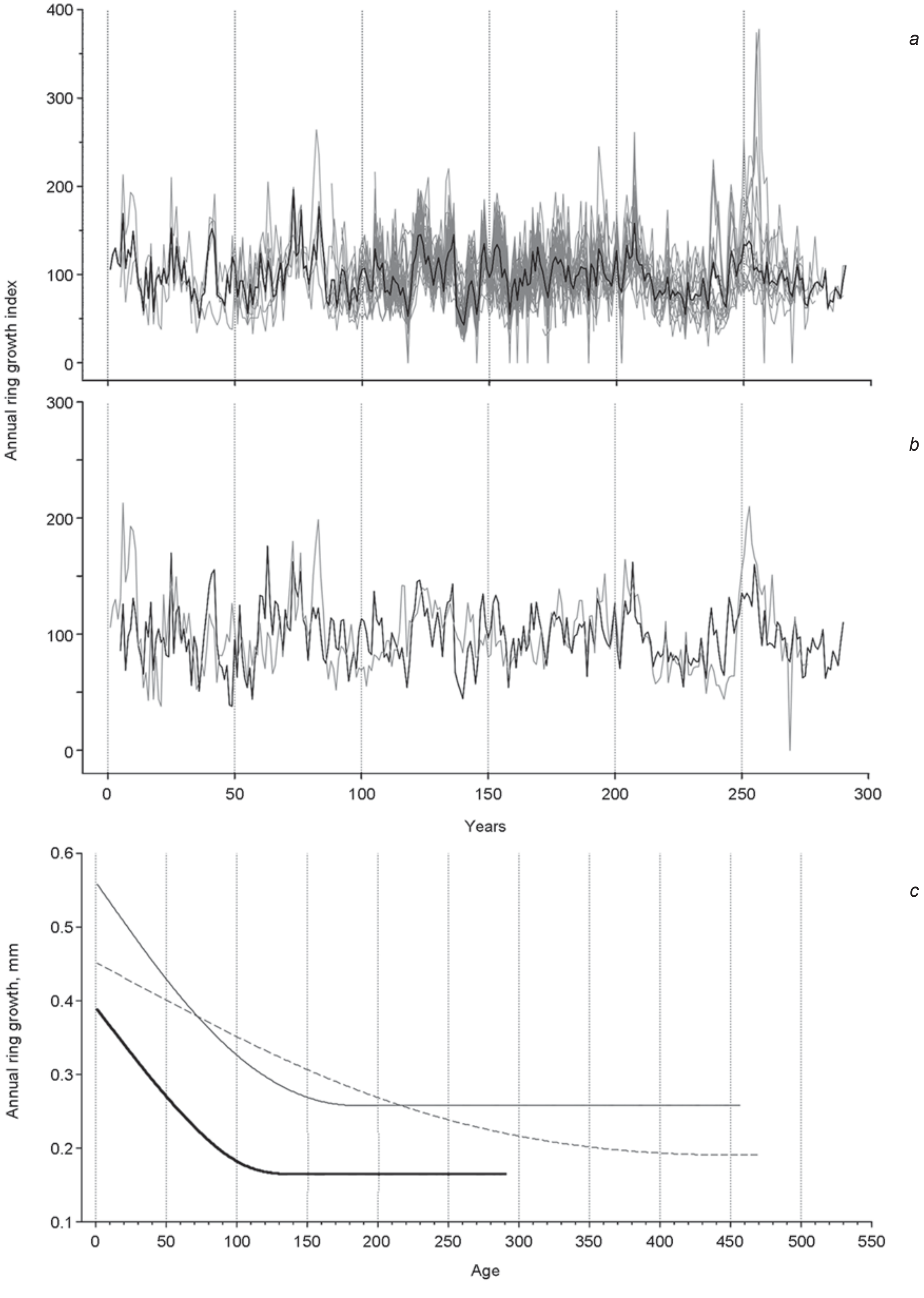

Fig. 4. Chronology 1_4.
a – individual growth series (gray line) and standardized generalized chronology built from them (black line); *b* – cross-dating of generalized growth series for charcoals from Kuekhtonar (black line) and Yustyd (gray line); *c* – comparison of age curves obtained from charcoal (black line) and trees in the Kurai basin (Kur, gray line), and from growing trees and paleowood on the upper forest boundary of the Southern Chuya Range (Jelo, dotted line).

for dendrochronological studies. During that procedure, the missing rings and measurement errors were identified, followed by accessing digital images; the presence or absence of the annual ring was checked, and measurements were adjusted. The age trend of the measured series was removed by two-thirds spline standardization (Cook, Krusic, 2008). This method was chosen owing to the presence of short periods with sharp increase in growth in individual samples (which is typical of the trees from the forest-steppe zone). The quality of the constructed chronologies was assessed using traditional indicators, such as correlation coefficients (multiple and Pearson), sensitivity, standard deviation, EPS, RBAR, etc. (Wigley, Briffa, Jones, 1984).

Results

360 out of 448 samples were suitable for measuring the linear parameters of growth rings. Tree species were identified by comparing the diagnostic features with keys from the reference book "Anatomy of Russian Woods" (Benkova, Schweingruber, 2004). It has been established that the species was *Larix sibirica* Ledeb (Siberian larch) of the *Pinaceae* (Pine) family. The samples were measured, after which ten referential samples were selected from individual growth series by such parameters as length and stability of growth (absence of short-term periods of sharp increase in the width of annual rings, presumably of non-climatic origin). At the first stage, cross-dating of the rest of the samples was done for each of these series, resulting in ten groups of cross-dated individual growth series used for constructing separate averaged chronologies. Their comparison with each other has shown that only two (No. 1 and 4) chronologies could be cross-dated and combined into a single common 1_4 chronology (Fig. 4, *a*). At the second stage, the obtained groups of samples were subjected to a standardization procedure. By averaging individual differences, the standardized chronologies better reflect the overall signal associated with changes in the external conditions of tree growth. Previously undated individual growth series were again cross-dated against standardized chronologies, which resulted in nine tree-ring chronologies based on 160 samples (see *Table*), that is approximately on 44 % of the total number of the measured samples (Fig. 5).

Parameters of tree-ring chronologies

Tree-ring chronology	Site	Height above sea level, m	Number of samples	Duration of tree-ring chronology, years		Average length of the series, years	Width of annual ring, mm		Correlation coefficient between the series	Sensitivity	Standard deviation
				Length	Range		Mean	Max			
1_4	Kuekhtonar, Yustyd		106	290	0–289	67	0.31	1.43	0.64	0.19	0.24
2	"		13	176	0–175	81	0.32	2.13	0.74	0.28	0.31
3	Yustyd	2100	9	76	0–75	37	0.33	1.08	0.55	0.26	0.28
5	"	2100	2	83	0–82	58	0.27	0.57	0.78	0.32	0.35
6	"	2100	3	108	0–107	88	0.16	0.58	0.64	0.21	0.26
7	"	2100	3	99	0–98	82	0.17	0.46	0.41	0.18	0.26
8	Kuekhtonar, Yustyd		13	115	0–114	60	0.24	0.94	0.51	0.18	0.22
9	Yustyd	2100	7	117	0–116	88	0.17	1.02	0.72	0.34	0.32
10	"	2100	4	175	0–174	95	0.20	0.69	0.45	0.18	0.22
	Total	–	160	1239	–	68	–	–	0.60	–	–
Kur	Kurai steppe	1550	30	457	1559–2015	302	0.37	4.10	0.72	0.337	0.379
Jelo	North-Chuya Ridge	2400	130	1900	112–2011	392	0.31	2.77	0.704	0.271	0.297

Note. Tree-ring chronologies 1–10 are based on charcoal from iron-smelting furnaces, Kur – on trees for forest-steppe areas, Jelo – on trees for the upper forest boundary (North-Chuya Ridge).

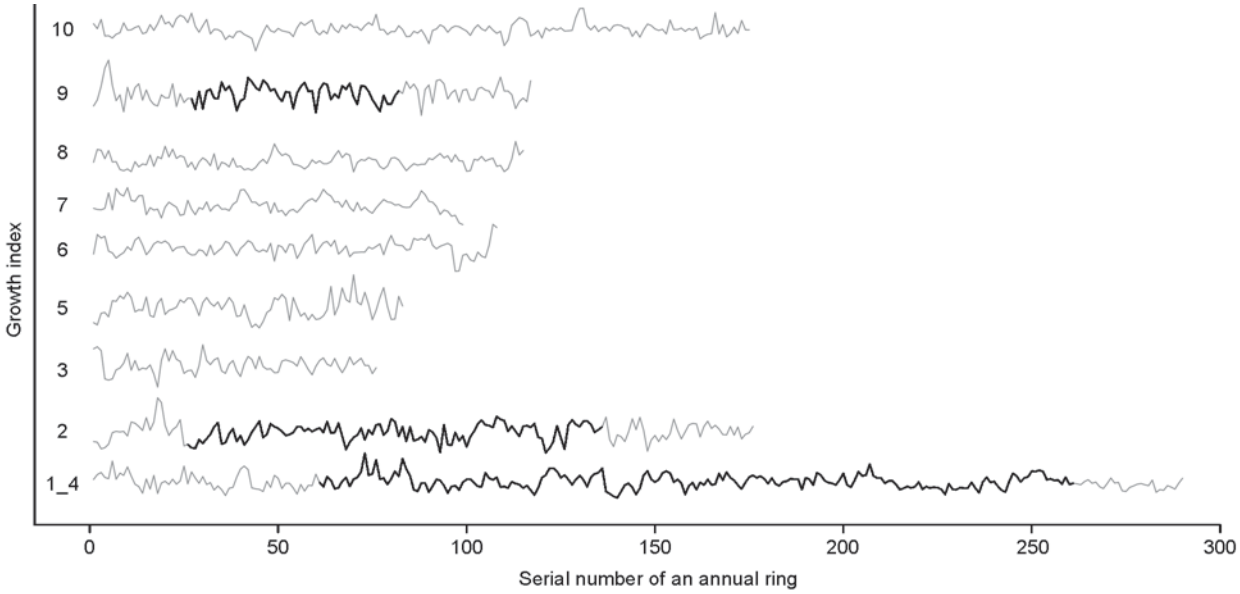

Fig. 5. Generalized standardized chronologies (gray lines) generated using charcoals from Kuekhtonar and Yustyd. Black line marks the period with EPS ≥ 0.85.

Analysis of the samples that could not be dated has revealed that usually these were series with a small number (less than 20–30) of annual rings, or long series with deviations in growth. In the future, with new evidence, it may theoretically become possible to accomplish their cross-dating.

The number of dating samples in the chronologies was uneven. The most representative was the combined tree-ring chronology 1_4 (106 samples); the least representative was chronology 5 (two samples). The length of the obtained standardized tree-ring chronologies varied from 76 to 290 annual rings; the correlation coefficient between the series ranged from 0.41 to 0.78, but these indicators do not depend directly on the saturation degree of chronologies with samples. Such a parameter as average length of series in a tree-ring chronology varied from 37 to 95 tree rings (see *Table*). The EPS parameter was significant for three chronologies, which means that growth reflected the signal of the general totality: No. 1_4 – at the interval of two hundred years, No. 2 – 110 years, and No. 9 – 55 years (Fig. 5). Since nine tree-ring chronologies could not be cross-dated with each other, it can be assumed that continued work with charcoals from the Kuekhtonar and Yustyd sites may result in constructing at least a 1200-year tree-ring chronology for the steppe and forest-steppe areas of these depressions, where a lack of precipitation is the hampering factor for the growth of woody vegetation.

An unexpected result was the fact of cross-dating of charcoals not only from one furnace, but also from the furnaces located at Kuekhtonar and Yustyd (see Fig. 4, *b*). Despite the distance of 82 km (in a straight line) between these sites, and the difference between their hypsometric marks reaching 350 m, the samples from Kuekhtonar and Yustyd (u2 and u3, u3, u2, respectively) were dated in chronologies 1_4, 2, and 8. This fact indicates the homogeneity of climatic conditions for tree growth in the Kurai and Chuya basins (resulting from the lack of precipitation as a common limiting factor). Notably, charcoal from furnaces at the Kuekhtonar and Yustyd sites revealed the minimal difference in the time between the emergence of peripheral rings. For example, it was 14 years in chronology No. 1_4 (samples u3_32 and kk48, a later date for charcoals from Kuekhtonar), 22 years in chronology No. 2 (samples k2_56 and u3_22, a later date for charcoals from Yustyd), and one year in chronology No. 8 (samples u2_27 and kk181, a later date for charcoals from Kuekhtonar). These results suggest that iron-smelting furnaces were used at about the same time.

The following pattern was observed in the distribution of samples from Kuekhtonar and Yustyd for other chronologies: No. 3 was represented by the samples from furnaces 2, 3, and 5 at Yustyd (u2, u3, and u5); No. 5 from furnace 2 at Yustyd (u2); No. 6 from furnace 5 at Yustyd (u5); No. 7, 9, and 10 were samples from the Kuekhtonar furnace.

Discussion

Our experience in dendroarchaeology clearly shows that the increased availability of professional equipment and ongoing digitization may lead to a higher quality in measurements, expanded opportunities in using sample preparation methods, and the emergence of new methods. Therefore, the dendrochronological method may be used for analyzing the evidence that had been previously considered unsuitable for processing, and it becomes possible to use charcoal to design thousand-year long tree-ring chronologies in the forest-steppe zone. The undoubted advantages of our approach include a significant reduction in the costs of equipment, increased accuracy of measuring annual rings, new opportunities for full-capacity remote work on measuring samples (you can only install the specialized CooRecorder software on a suitable PC), removing the verification problem (the quality of measurements on the image can be easily verified by independent scholars), and expanding the range of measurable parameters of the annual ring (one may simultaneously establish the width of the ring, its early and late parts, optical density, etc.). Noteworthy is that the resulting image captures the cellular structure of the sample at the moment of its optimal state (the quality of the surface obtained during sample preparation inevitably decreases with time, so in the future, there will be no need to waste time on repeated preparation).

Our approach to charcoal sample preparation has clearly shown that, unlike the common opinion, this type of evidence has a great capacity for constructing a long tree-ring chronology. Our results demonstrate a realistic opportunity to elaborate a continuous 1200-year-long tree-ring chronology. Its estimated duration is in good agreement with radiocarbon dates of charcoals from the Kuekhtonar furnaces (Vodyasov et al., 2020). The ^{14}C-dates obtained corresponded to a wide chronological range from the mid 1st millennium BC to the 1st millennium AD. In our opinion, such scatter is associated with the “old tree effect”. The presence of a subcrustal ring, which directly indicates the time of three harvesting, is of key importance when dating wood. Yet, in the case of charcoal, it is extremely difficult to establish the number of the lost peripheral rings. Therefore, radiocarbon dates do not reflect the actual age of the dated objects, which are in fact younger by the time corresponding to the missing tree rings. The conventional approach to solving this issue is to select the samples of charcoals for radiocarbon dating with width of annual rings indicating the proximity of the subcrustal ring. In this case, the group of the latest close dates is taken as the year of timber harvesting (Ibid.). In our opinion, this approach should be used with great caution, since radiocarbon dating without constructing a tree-ring chronology based on the samples from the site significantly increases the likelihood of error.

To confirm this point, we analyzed the age-growth curve (reflecting a decrease in the effect of endogenous and an increase in the effect of exogenous factors as the age of the trees increases, which leads to stabilization of annual growth) and life expectancy of trees in the past and present in the area under study. For example, the growth of living trees stabilizes approximately at the age of 150 years (see Fig. 4, *c*), while the maximum recorded survival-age of trees in the Kurai steppe is over 450 years (see *Table*). The samples from the charcoal collection with the preserved central ring were used for estimating the age-curve for paleotrees. It should be mentioned that dynamics of changes in growth in the past (obtained from charcoal) correlates well with the age-curve of trees growing at the present time (see Fig. 4, *c*). However, there are also some differences. For instance, the average growth of trees in the past was somewhat smaller and its stabilization occurred at an earlier age, which indicates a more severe growing environment for paleotrees used as fuel in iron-smelting furnaces.

The experience of dendrochronological studies shows that trees live longer in a more severe environment (Büntgen et al., 2019). However, the average age established from the measured charcoal samples was 68 years, while the age of the currently growing trees exceed 300 years. If this is the case, charcoals lack a significant number of growth rings. As is shown by the above analysis, paleotrees grew in more severe (arid) environment, which means that their maximum age should be greater than that of the modern trees. For example, the maximum age of trees growing in the Ubs Nuur Basin in the neighboring Republic of Tuva, with more severe (arid) conditions, reaches 778 years (Tainik et al., 2022). On the basis of this observation, it can be assumed that features of growth stabilization in charcoals are not reliable evidence for the close proximity of the subcrustal ring. In our opinion, the only way to avoid wide scatter of radiocarbon dates is to conduct a preliminary dendrochronological analysis of the samples.

The source of wood that was used in iron-smelting furnaces at Yustyd and Kuekhtonar is of great importance. Next to the Kuekhtonar site, there is a larch forest now. A completely different situation is that at the Yustyd site, where trees do not grow today. However, there are reasons to believe that forests could have been there in the past. For example, the name of the Yustyt River can be translated as “one hundred larches” (Molchanova, 1979: 186). At present, individual larch trees grow in the floodplain upstream of the river, and small larch-groves grow 4 km south of the site with iron-smelting furnaces, on the slope of the northern exposure at an altitude reaching 2400 m above sea level. In this case, one should take into account the process of the increasing climate aridization, which resulted in changes in the area of woody vegetation in the eastern part of the Chuya basin over the past one and a half to two millennia (Agatova et al., 2016; Churakova et al., 2022), as well as wood-harvesting by nomads for their everyday needs (Agatova, Nepop, Korsakov, 2017; Agatova, Nepop, Slyusarenko, 2017). Since the climate used to be less arid than it is now, the southern slope of the valley was likely covered with forest, which could have descended down the stream, almost reaching the furnaces. In this case, there was also no problem with charcoal wood at the Yustyd site.

In order to establish the source of wood used for metal-smelting, it was necessary to compare the parameters of chronologies obtained from charcoal (the most representative chronology 1_4, which included 99 samples from Kuekhtonar and seven samples from Yustyd, was chosen for comparison), and tree-ring chronologies generated for the steppe part of the Kurai basin (Kur) and the upper forest boundary (Jelo) (Myglan, Zharnikov, Malysheva et al., 2012). The comparison has revealed that all parameters of chronology 1_4 (the mean and maximum width of growth ring, correlation coefficient between the series, sensitivity, and standard deviation) were significantly lower than those of the Kur forest-steppe tree-ring chronology (see *Table*). This suggests a more severe growing environment for the trees used for metal production. A somewhat different situation was observed when comparing with the Jelo tree-ring chronology for the upper forest boundary. Such parameter as the average width of the annual ring had the same values; the remaining parameters of chronology 1_4 were lower (see *Table*). Thus, in terms of its characteristics, tree-ring chronology 1_4 was closer to the chronology of the upper forest boundary (Jelo) than to the chronology of the modern trees from the steppe zone of the Kurai basin. It would seem that this may indicate the harvesting of wood for iron-smelting furnaces high on the slope. However, comparison of age-curves of tree growth (dynamics of decrease in growth and growth stabilization time) has revealed that age-curves obtained for charcoal and trees growing in the Kurai steppe were similar, and radically differed from those constructed for the upper forest boundary (see Fig. 4, *c*). Tree-ring chronologies built on charcoals did not correlate with the super-long mountain chronologies of Jelo and Mongun (Ibid.; Myglan, Oidupaa, Vaganov, 2012) owing to the effect of various inhibiting factors at the upper limit of tree vegetation and in the forest-steppe zone of the Southeastern Altai, which is in good agreement with analytical data obtained for the adjacent areas in the Republics of Tyva and Buryatia, and the Trans-Baikal Region. In this case, the trees growing on the upper forest boundary could not have been the source of wood for iron-smelting furnaces.

Notably, the construction of a thousand-year tree-ring chronology for the arid zone of Southern Siberia, which is based on charcoal, is of fundamental importance. In terms of practical application, its calendar correlation will make it possible to establish accurately the time when iron-smelting furnaces operated. More broadly, further research will draw on archaeological wood (charcoal) as an important source of ecological and paleoclimatic information. In addition, tree-ring chronology of such duration will lay a solid foundation for calendar dating of wood-samples from numerous burial mounds located in the steppe regions of the Altai Republic, and will open up broad prospects for performing reconstructions of humidification in the area under study with high (annual) resolution.

Conclusions

Thus, the development of a new approach to the study of charcoal from metallurgical furnaces in the Southeastern Altai and the introduction of advanced methods for analyzing dendrochronological data open up new prospects for exploring climate change and the cultural heritage of the past. Further research will provide the opportunity of solving the fundamental problem associated with the elaboration of a long tree-ring chronology in the arid zone of Southern Siberia (today, the longest tree-ring chronology in this zone extends back only 778 years). Consequently, the creation of a tree-ring chronology based on charcoal and covering the 1st millennium AD, and its calendar reference, will make it possible to elaborate a 2000-year tree-ring chronology for the steppe belt of Southern Siberia for the first time. Such chronology would be a unique tool for solving a wide range of practical problems, including the caldendar dating of wood from numerous burial mounds located in the intermountain depressions of the Altai-Sayan region, the reconstructing of annual moisture regimes, and the identifying the frequency of extreme droughts and other natural phenomena in this region.

Acknowledgments

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