Radiocarbon, Vol 56, Nr 3, 2014, p 1195–1206 DOI: 10.2458/56.17500

VARIABILITY IN RADIOCARBON DATES IN MIDDLE PLENIGLACIAL WOOD FROM KURTAK (CENTRAL SIBERIA)

P Haesaerts[1,2] • F Damblon[1] • N Drozdov[3] • V Checha[3] • J van der Plicht[4]

ABSTRACT. The chronology of long Upper Pleistocene loess sequences in Eurasia is based on combined pedostratigraphy and radiocarbon dating of high-quality charcoal. The accuracy of such a chronology depends on the reproducibility and precision of the ^{14}C dates. However, certain dates may show discrepancies with regard to their chronostratigraphic context based on series of coherent dates. In order to evaluate the consistency and variation in the ^{14}C dates obtained from small charcoal pieces, this question was tested on a set of spruce wood remains with well-preserved tree rings found in the Middle Pleniglacial loess-loam sequence of Kurtak (central Siberia). Tree-ring analysis of five fairly large wood pieces from three successive layers, dated to about 30.0, 30.8, and 32.2–32.5 ka BP previously, was done by continuous sampling of 90–150 rings on each wood piece. This enabled direct comparison of the succession of tree rings with the ^{14}C dates. A total of 133 dates was obtained for the five wood pieces. The results show fluctuations in the ^{14}C dates within a time range between 1000 and 2000 yr. Four possible causes for such variation will be discussed herein: (1) internal variability of the AMS dating method; (2) outliers; (3) variations in the ^{14}C background; and (4) external factors such as past atmospheric ^{14}C variations.

INTRODUCTION

The loess-loam deposits of Eurasia are good archives recording evidence of past climatic oscillations during the Upper Pleistocene. Long, detailed pedosedimentary and climatic sequences have been obtained for the Middle Pleniglacial in eastern Europe and Russia. The chronology of each sequence has been determined in recent decades by large series of radiocarbon dates on high-quality charcoal preserved in Upper Paleolithic sites during the 40–25 ka BP period (Haesaerts et al. 2005, 2009, 2010). However, within these coherent chronological sequences, some dates on charcoal showed clear discrepancies (more than 2σ) compared with their chronostratigraphical background (Damblon and Haesaerts 2007). Such discrepancies have also been recorded for the 30–34 ka BP period in terrestrial and oceanic sequences, possibly as a consequence of microwiggles in the variations of the atmospheric ^{14}C content (Kitagawa and van der Plicht 2000; Voelker et al. 2000; Beck et al. 2001; Conard and Bolus 2003).

Therefore, the question was raised how to control the reproducibility and constancy of ^{14}C dates obtained on small fragments of wood or charcoal remains with only a few (generally 1 to 5) tree rings. One way to achieve this goal was to test the degree of constancy or variability of long series of dates on old tree rings. This is a difficult problem for the period 30–34 ka BP due to the relative scarcity of well-preserved wood material allowing both counting of tree rings and ^{14}C dating (Turney et al. 2007, 2010; van der Plicht et al. 2012).

A unique opportunity to test the reproducibility of large sets of ^{14}C dates comes from the site of Kurtak (central Siberia), close to the Yenisei River (Figure 1). Here, large and well-preserved wood remains have been recovered in a long Middle Pleniglacial loess-loam sequence. In the Chani P31 sections, pedostratigraphy and palynology show evidence for seven events of climatic improvement, well dated on wood remains between 37 and 26 ka BP (Figure 1; Haesaerts et al. 2005, 2009, 2010). This article compares the ^{14}C results obtained on five wood pieces positioned in three subunits of which wood remains were dated previously between 30.0 and 32.5 ka BP. Our study discusses 133 accelerator mass spectrometry (AMS) dates, including many duplicates, produced on small wood sample blocks from the tree ring sequences, with the goal of analyzing the reproducibility and consistency of the results.

1. Royal Belgian Institute of Natural Sciences, Brussels, Belgium.
2. Corresponding author. Email: paul.haesaerts@naturalsciences.be.
3. Institute of Archaeology and Ethnography, Academgorodok, Krasnoyarsk, Russia.
4. Center for Isotope Research, Groningen University, Nijenborgh 4,9747 AG Groningen, the Netherlands. Also: Faculty of Archaeology, Leiden University, PO Box 9515, 2300RA Leiden, the Netherlands.

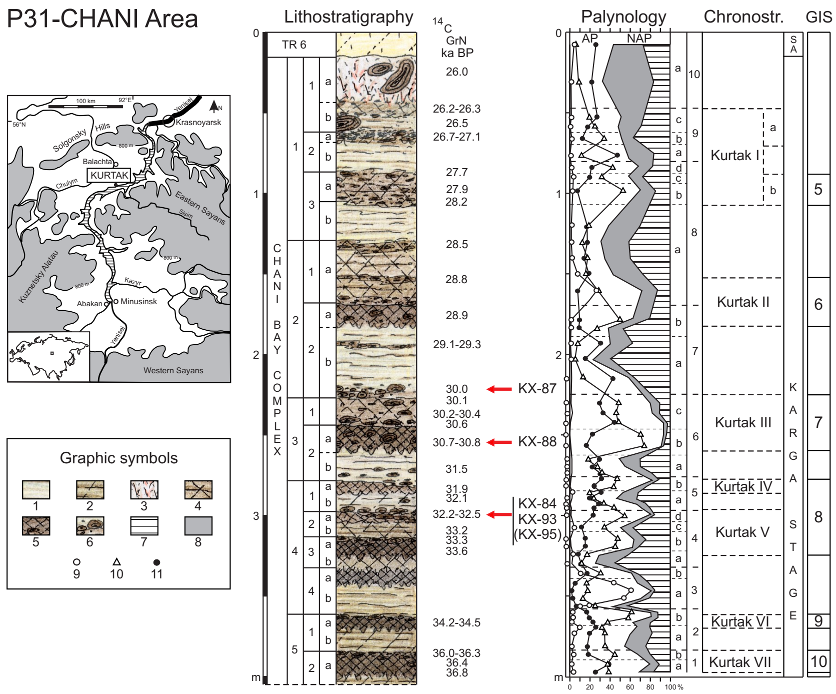

Figure 1 The Middle Pleniglacial loess sequence of Kurtak and position of the spruce wood pieces recovered from three subunits of the Chani Bay Complex. Symbols: 1: loess; 2: loam; 3: tundra gley; 4: weak humic loam; 5: humic loam; 6: wood remains; 7: Poaceae pollen, 8: pollen of other herbs, 9: *Betula* pollen, 10: *Picea* pollen, 11: *Pinus* pollen; GIS: Greenland Interstadial. Arrows: position of the wood pieces for dating tree-ring sample blocks (redrawn from Haesaerts et al. 2005, 2010).

METHODS

Wood Material and Tree Rings

In 2000, in the P31-Chani section, four large pieces of wood were collected in precise stratigraphic position (Figure 1): KX-87 at the top and KX-88 at the bottom of the Kurtak III Interstadial (~30–31 ka BP), and KX-84 and KX-93 in the upper part of the Kurtak V Interstadial (between ~32–32.5 ka BP). In particular, the wood piece KX-93 was collected from the proximal part of a root still connected to a stump preserved *in situ*. A fifth wood fragment (KX-95) was found at the base of the P31 section directly below the subunit attributed to the Kurtak V Interstadial. Botanical analysis of the wood suggests *Picea obovata* as the most likely species.

Five sets of AMS dates on tree rings from the five spruce wood pieces measured at different times (2002 and 2012, termed "series of dates") are discussed in terms of consistency and reproducibility of the results. Measurement of the ring widths was done at the University of Liège Laboratory of Dendrochronology (Belgium), along the longest diameter to more easily follow the sequence of the rings (Figure 2). For each wood piece, the main episodes with wider ring widths were numbered in succession (P1, P2, etc.), referring to the identification label of the wood pieces (Figures 3 to 8). For wood piece KX-95, the start of the numbering of the rings close to the center is somewhat arbitrary due to the partial decay of the wood, but the sequence of the rings for ^{14}C dating could still be determined.

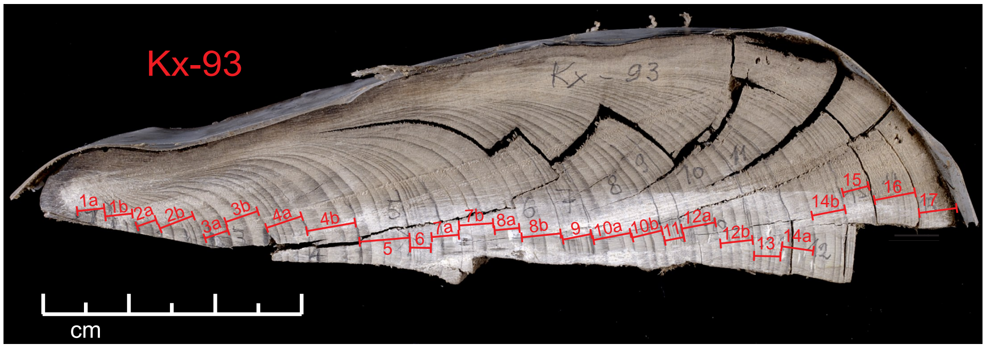

Figure 2 Section of spruce wood piece KX-93 showing the tree rings and the succession of wood sample blocks for ^{14}C dating.

The ^{14}C Samples

Each wood piece (containing 90 to 150 rings) was cut into successive small blocks of 5–10 rings. Thus, 13 to 18 sample blocks, precisely positioned in the tree-ring sequence, were taken from each of the wood pieces (black and white bars in Figures 3 to 8).

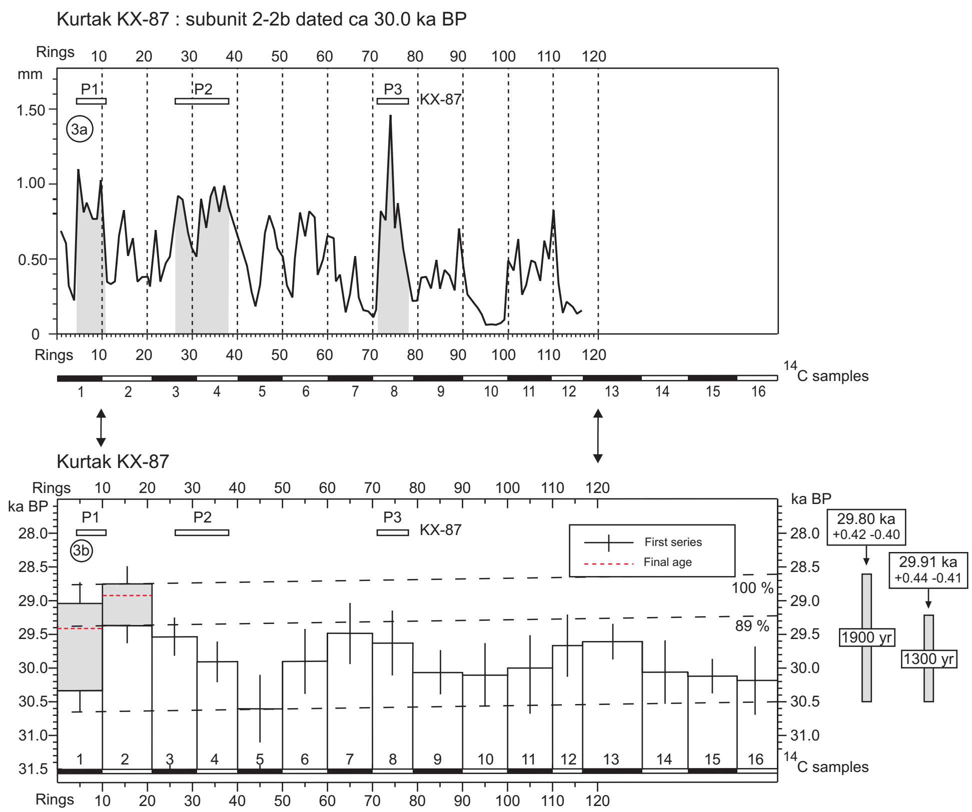

Figure 3 (a) Variability in tree-ring widths in wood piece KX-87. The main peaks of ring widths are marked by white bars labeled P1, P2,… (b) Distribution of the ^{14}C dates of the first series from KX-87. The position of the peaks of ring widths is given with regard to the tree-ring sequence and the ^{14}C samples. The two dashed lines through the curve show the 100% limit of variations in the dates from KX-87 within a time range of 1900 yr. The two shaded areas show the differences between the two double dates, while the subhorizontal dashed lines indicate the final ages for each sample block.

https://doi.org/10.2458/56.17500 Published online by Cambridge University Press

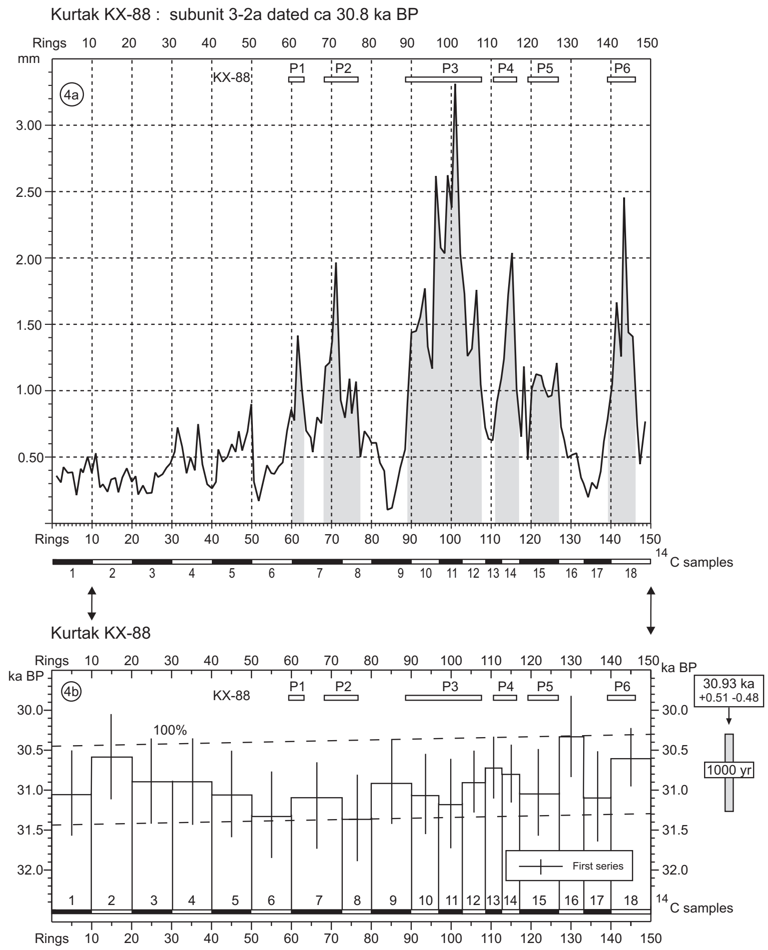

Figure 4 (a) Variability in tree-ring widths in wood piece KX-88. (b) Distribution of the ^{14}C dates of the first series of KX-88 relative to the tree-ring sequence. The two dashed lines through the graph show the 100% limit of variations in the dates from KX-88 within a time range of 1000 yr. Symbols and labels of 4a and 4b are the same as in Figure 3.

In 2002, two series of 107 dates, including duplicates on KX-84, KX-93, and KX-95 and two double dates on KX-87, were dated (series 1 and 2), with each wood piece showing a specific distribution of the dates (Figures 3 to 7). In 2012, a new additional continuous series of 14 samples (series 3) was analyzed from the middle part of KX-93 to test the constancy of the 2002 set of dates (Table S1 in the online supplementary material and Figures 7c and 8). The wood samples were all dated by AMS in the Groningen ^{14}C Laboratory.

RESULTS: TREE-RING SERIES AND SAMPLE BLOCKS FOR DATING

Below, we show how the samples were marked. The sequence of the tree-ring width peaks (P1, P2,…) makes this process easier.

KX-87: base of subunit 2-2b (Figure 3a)

In total, 116 rings were measured, showing relatively small variations in width (mainly between 0.3 and 1 mm). The most recent rings could not be counted and measured due to decay of the outermost rings. The plot clearly shows alternating phases with narrow or wider rings, most around 6 to 10 yr, suggesting a cycle in the sequence. Three main specific peaks (P87-1, P87-2, P87-3) can be defined from the ring series. The whole wood piece provided 16 sample blocks of around 10 rings for ^{14}C dating (Figure 3).

KX-88: base of subunit 3-2a (Figure 4a)

The plot shows 149 rings, varying strongly in width between 0.1 and 3.3 mm. After an initial phase with narrow rings lasting about 60 yr, the tree growth then shows an increase with six phases of wider rings (P88-1 to P88-6) alternating with very thin rings (often <0.3 mm). The highest peak is located at ring 102 (P88-3). This is interpreted as a consequence of slow tree growth conditions with very thin rings found between P88-2 and P88-3, and between P88-5 and P88-6. The whole wood piece provided 18 sample blocks of 5 to 12 rings, depending on wood density, for ^{14}C dating (Figure 4).

KX-84: subunit 4-2a (Figure 5a)

The plot shows 96 rings with a signature different from those of KX-87 and KX-88, showing two sets of medium-size peaks (respectively, P84-1 and P84-2; P84-3 and P84-4) separated by a rather long set of about 20 very small rings. The wood piece provided 13 sample blocks of 4 to 10 rings, depending on wood density, for ^{14}C dating (Figure 5).

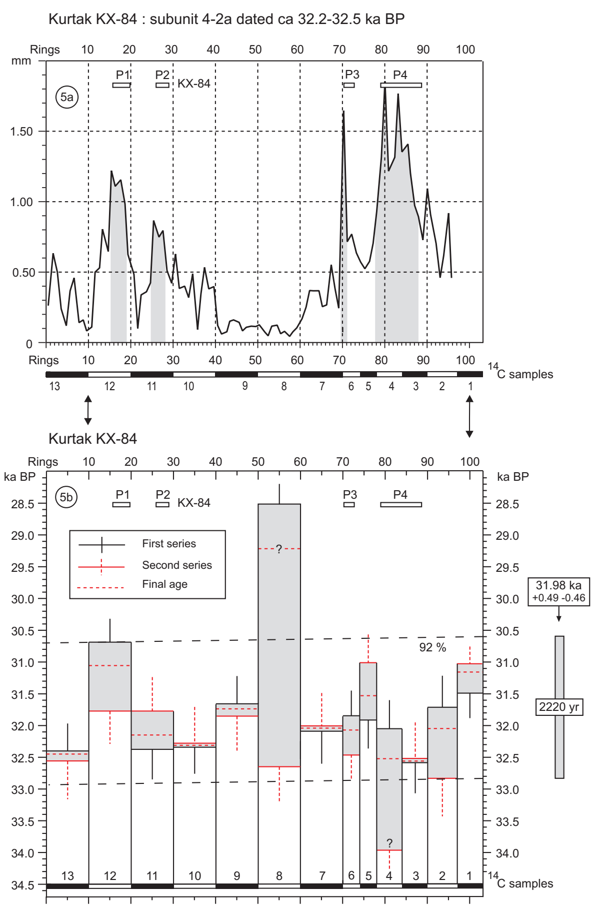

Figure 5 (a) Variability in tree-ring widths in wood piece KX-84. (b) Distribution of the ^{14}C dates of the first and second series of KX-84 relative to the tree-ring sequence. The dashed lines show the 92% limit of variations in the dates from KX-84 within a time range of 2220 yr. Symbols and labels of 5a and 5b are the same as in Figure 3.

https://doi.org/10.2458/56.17500 Published online by Cambridge University Press

KX-95 not *in situ* (Figure 6a)

After a starting phase with narrow rings (mostly <0.5 mm), strong variations are visible in ring width: sharp peaks up to 2.5–3 mm (P1 to P6), followed by narrow rings down to <0.5 mm. KX-95 shows 147 rings, but the inner part of the wood was degraded, so that only 12 sample blocks of rings could be collected for ^{14}C dating (Figure 6b).

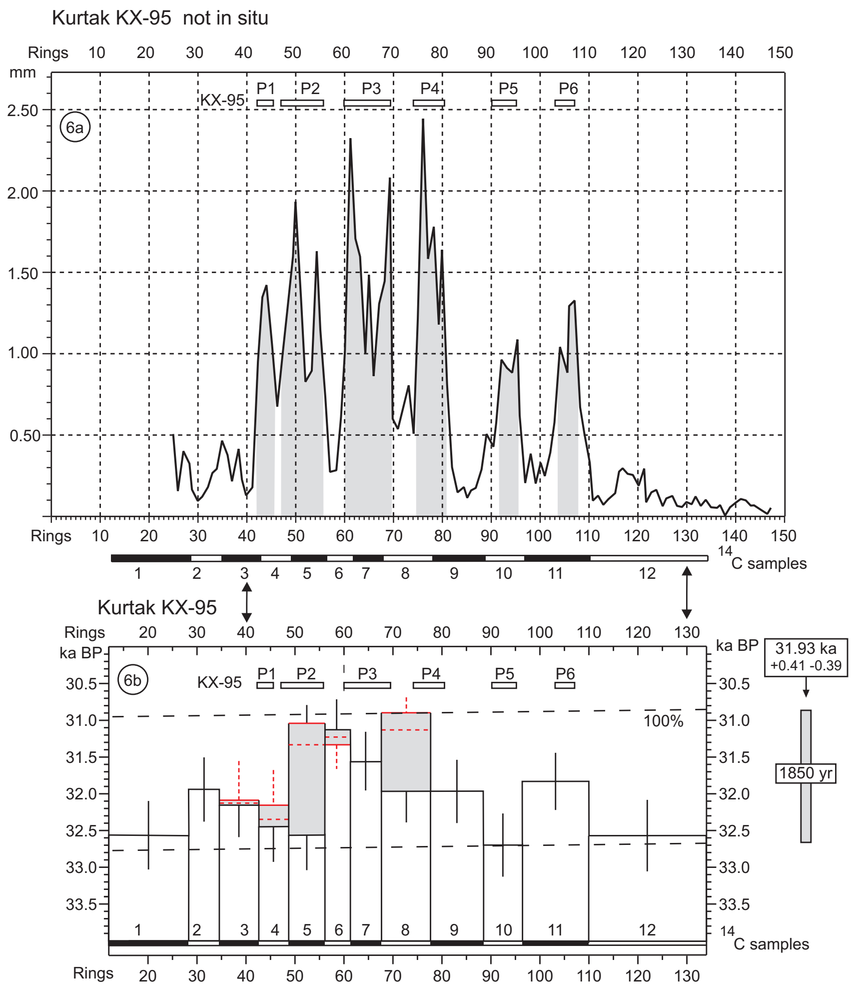

Figure 6 (a) Variability in tree-ring widths in wood piece KX-95. The main peaks of ring widths are marked by white bars labeled P1, P2,… (b) Distribution of the ^{14}C dates of the first and second series of KX-95 relative to the tree-ring sequence. The dashed lines show the 100% limit of variations in the dates from KX-95 within a time range of 1850 yr. Symbols and labels of 6a and 6b are the same as in Figure 3.

KX-93 subunit 4-2a (Figure 7a)

The plot shows 140 well-preserved rings, enabling ^{14}C dating of 17 sample blocks of 4 to 20 rings depending on the position and density of the rings (Figure 7b). Fourteen ring blocks were submitted for duplicate dating in 2012 (Figures 7c, 8a, and 8b).

The ring width plots of KX-87, KX-88, KX-84, and KX-93 appear clearly different, the first two

https://doi.org/10.2458/56.17500 Published online by Cambridge University Press

wood pieces coming from two successive stratigraphic subunits 2-2b and 3-2a while the latter two come from lower subunit 4-2a (Figure 1). The KX-95 wood was not recovered *in situ*, but its signature appears very similar to that of KX-93. This suggests that KX-95 also comes from subunit 4-2a.

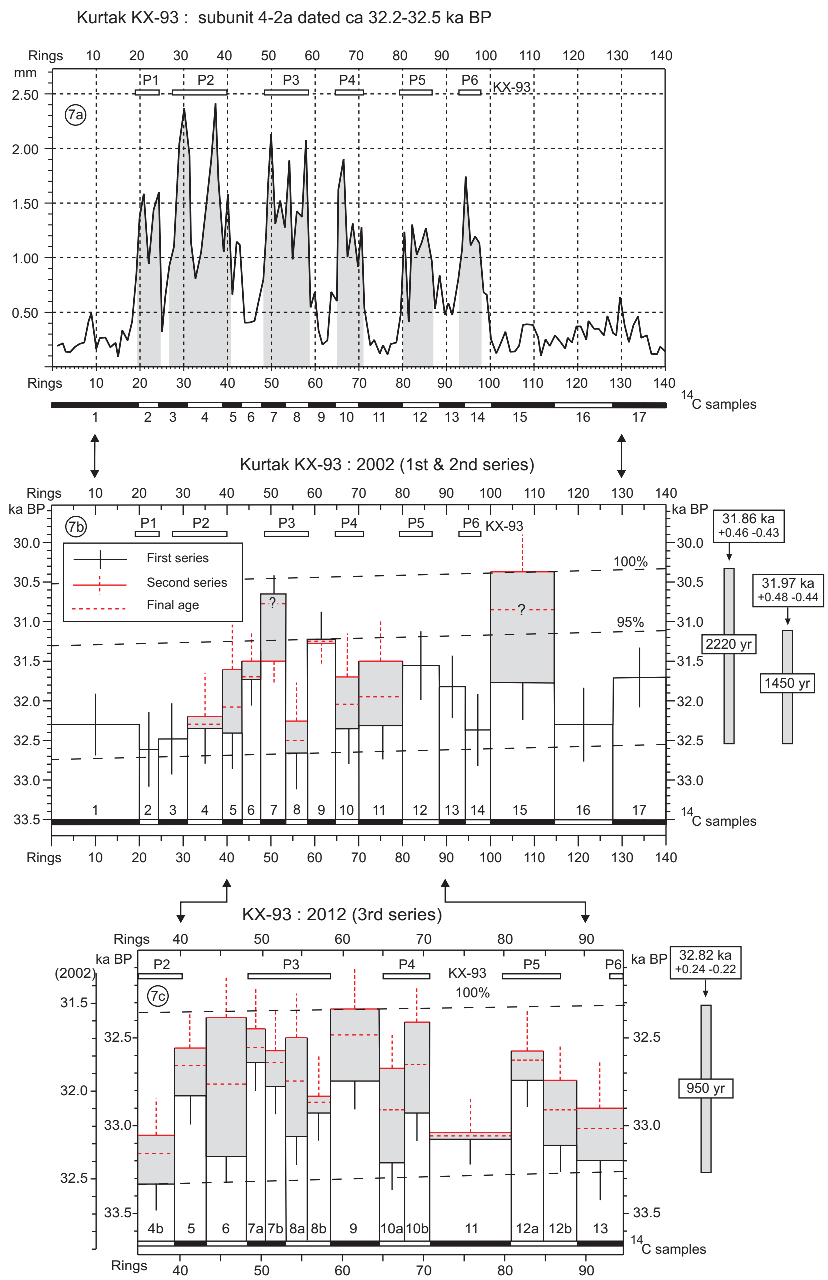

Figure 7 (a) Distribution of the peaks in ring widths in wood piece KX-93. (b) Distribution of the ^{14}C dates of the first and second series of KX-93 relative to the tree-ring sequence. The dashed lines show the 95% limit of variations in the dates from KX-93 within a time range of 1450 yr. Symbols and labels of 7a and 7b are the same as in Figure 3. (c) Distribution of the ^{14}C dates of the third series of KX-93. The dashed lines show the 100% limit of variations in the dates from KX-93 within a time range of 950 yr.

https://doi.org/10.2458/56.17500 Published online by Cambridge University Press

RADIOCARBON DATES

In total, 133 dates on five wood pieces (KX-87, -88, -84, -93, -95) were obtained for three distinct successive series (Table S1):

- First series: 78 dates, series GrA-18098 to -18219 (in 2002);
- Second series: 27 dates, series GrA-20315 to -20384 (in 2002);
- Third series: 28 dates, series GrA-50470 to -50837 (in 2012).

The distribution of these series of dates is as follows:

- KX-87: (about 160 rings) base of subunit 2-2b previously dated to ~30.0 ka BP on other wood material (Figure 1; Haesaerts et al. 2005). We measured 16 dates on cellulose (first series) and two double dates on wood (first series) (Figure 3).
- KX-88: (150 rings) base of subunit 3-2a previously dated to ~30.8 ka BP on other wood material (Figure 1; Haesaerts et al. 2005). We measured 18 dates on cellulose (first series) (Figure 4).
- KX-84: (105 rings) upper part of subunit 4-2a previously dated to ~32.2–32.5 ka BP on other wood material (Figure 1; Haesaerts et al. 2005). We measured 13 dates on cellulose (first series) and 13 duplicates (second series) (Figure 5).
- KX-95: (115 rings) most probably upper part of subunit 4-2a previously dated to ~32.2–32.5 ka BP on other wood material (Figure 1; Haesaerts et al. 2005). We measured 12 dates on cellulose (first series) and 5 duplicates (second series) (Figure 6).
- KX-93: (145 rings) upper part of subunit 4-2a previously dated to ~32.2–32.5 ka BP on other wood material (Figure 1; Haesaerts et al. 2005) (Figure 7 and 8).

In 2002, 17 dates on cellulose (first series) and 9 duplicates (first and second series) were measured (Figure 7b). In 2012, 14 dates on cellulose and 14 duplicates (third series) were obtained (Figures 7c and 8b). The ring samples 4, 7, 8, 10, and 12 were radially subdivided into subsamples a and b (Figures 7c and 8b).

DISCUSSION

Tree Rings

The temporal distribution of the tree-ring data recorded at Kurtak for wood pieces from different stratigraphic positions, as well as the reproducibility of the signatures of KX-93 and KX-95, clearly suggest short time variations in the conditions of tree growth. Considering both the taxon (*Picea*) and the regional background (loess field in central Siberia), it is likely that the water supply in the soil was the main limiting factor for tree growth (Schweingruber 1996; Magda and Zelenova 2002; Juday et al. 2012).

Radiocarbon Dates

KX-87, first series (Figure 3b)

Wood piece KX-87 provides ^{14}C dates that all belong to the first series. The distribution of the dates shows a rather regular trend, except for the two dates on samples 1 and 2. The entire set of dates fits within a time range of about 1900 yr, taking into account the growing time of the trees (subhorizontal dashed lines). The mean value of the dates (29.8 ka BP) is quite consistent with the previous dates obtained for subunit 2-2b (30.0 ka BP, Figure 1). Notice that 89% of the dates fits within a time range of 1300 yr when the younger dates from samples 1 and 2, which appear out of the general trend, are discarded.

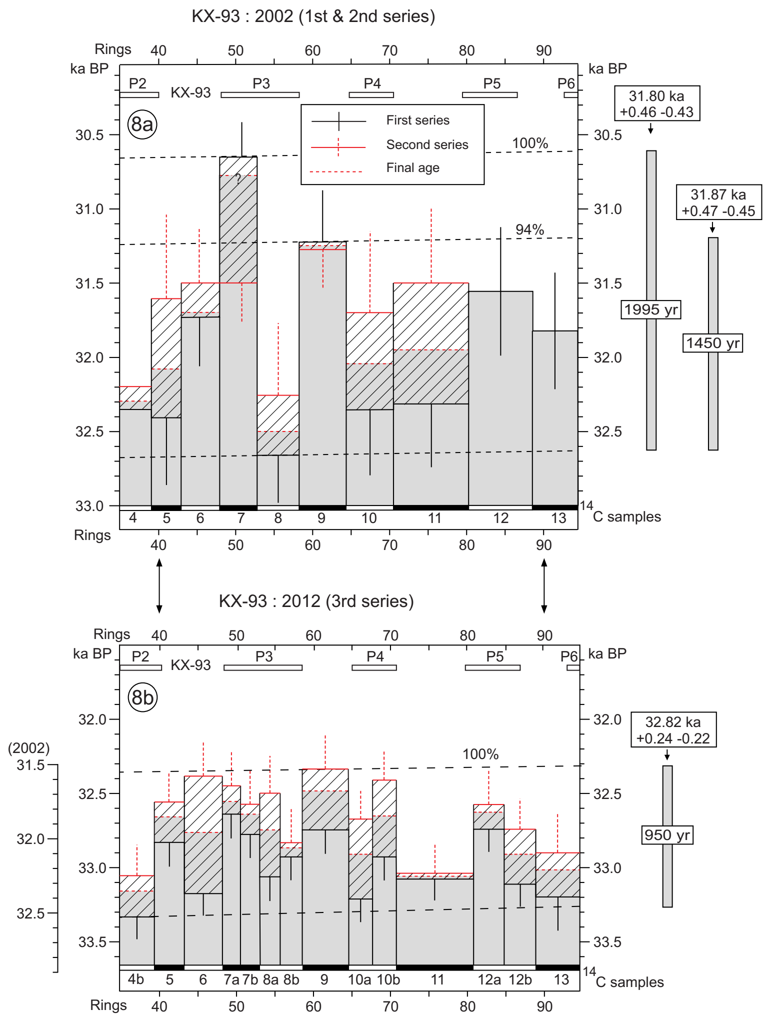

Figure 8 Distribution of the final ages (first, second, and third series) from KX-93 between ¹⁴C samples 4 and 13. (a) The dates and final ages of the first and second series (2002). The dates of the first series only are given for samples 12 and 13 because no duplicates are available for these samples. (b) The dates and final ages of the third series (see Figure 7c). The shaded areas show the variations in the final ages.

KX-88, first series (Figure 4b)

KX-88 provides a set of 18 dates distributed within a time range of about 1000 yr. Here again, the mean value of the dates (30.9 ka BP) corresponds very well with the previous dates for subunit 3-2a (30.8 ka BP, Figure 1).

KX-84, first and second series (Figure 5b)

In the two series of 13 dates, a large discrepancy can be seen for date nr 8 in the first series and for date nr 4 in the second series, both showing a jump of around 2σ relative to the other dates. Here, 92% of the dates fit within a time range of ~2220 yr (dashed lines). The mean value of the tree-ring dates is ~32.0 ka BP, which is consistent with the previous dates for subunit 4-2a (32.2–32.5 ka BP, Figure 1).

KX-95, first and second series (Figure 6b)

This piece of wood provides 17 dates in two series including five duplicates. At the 100% confidence level, the 17 dates fall within a time range of 1850 yr with a mean value of 31.9 ka BP, which is similar to that from KX-84.

KX-93, first and second series, 2002 (Figures 7b and 8a)

This piece of wood provides 26 dates in two series. Two samples (nr 7 in the first series and nr 15 in the second) produced dates outside the general trend of the other 24 dates, although they are within 2σ confidence. At the 95% confidence level, the 24 remaining dates fall within a time range of 1450 yr (Figure 7b). Together, the 24 dates form a homogeneous sequence covering the 140 rings of the wood piece. Also, here the mean value of 95% of the 2002 dates (32.0 ka BP) is within the range of the previous dates for Subunit 4-2a and is nearly identical to the mean values for KX-84 and KX-95.

KX-93, third series, 2012 (Figures 7 and 8)

In 2012, 28 dates including 14 duplicate dates (third series) were measured on the same wood material as samples nr 4 to 13 dated in 2002 (first and second series). Some of the samples were quite well preserved and large enough to be duplicated (nr 7a, 7b; 8a, 8b; 10a, 10b; 12a, 12b) in order to improve control of the reproducibility of the trend recorded in 2002. The entire set of dates of the third series appears to fall within a time range of ~950 yr, between ~33.3 and 32.3 ka BP. In this case, the mean value of the duplicate dates is around 32.8 ka BP, about 1000 yr older than the mean value of the 2002 series (Figure 7 and 8).

This difference between the 2002 and 2012 measurements is acceptable when we take into account the error margins of the two sets of dates. At 1σ confidence, only 28% of the dates of both sets show an overlap at the level of the corresponding samples; at 2σ confidence, the overlap is 83% (Table S1, KX-93 2002 and 2012). Furthermore, both set of dates for KX-93 show a parallel trend for the dates from samples 4b to 13 (Figure 8). This trend does not only show for the final ages, but also for the duplicates of series in 2002 and 2012.

CONCLUSION

At Kurtak, 133 ^{14}C dates were obtained for three successive series from tree-ring blocks sampled from five pieces of spruce wood from layers dated between about 30 and 32.5 ka BP. The analysis of the tree rings shows important variations in tree-ring widths, which make sampling the tree rings easier. The trends suggest significant variability in the conditions of tree growth during the period considered. The similar trends in wood pieces KX-93 and KX-95 suggest their common origin from the same layer.

Comparison of the distribution of the dates from the different pieces of wood and from the successive series of dates suggests four possible causes for the variations observed in the dates from each wood piece: (1) internal variability of the AMS dating method; (2) outliers; (3) variations in the ^{14}C background; and (4) external factors such as past atmospheric ^{14}C variations. It should be noted that no clear correlation is observed between the variations in the dates and the widths of the corresponding tree rings (Figures 3 to 7). Internal variability of the AMS measurements may be considered the main factor underlying the distribution of the dates in each series. Only four dates are outliers in KX-84 (nr 4 and 8) and KX-93 (nr 7 and 15) and can be discarded.

The time ranges corresponding to the distribution of the dates vary with the stratigraphic position of the wood pieces. For the period between 30 and 31 ka BP (Interstadial event Kurtak III), wood pieces KX-87 and KX-88 show a distribution of the dates (with a mean 1σ error of ~450 yr) within a time range from 1000 to 1300 yr. In contrast, for the period between 32 and 33.5 ka BP (Interstadial Kurtak V), the time range as measured in 2002 for samples KX-84, KX-93, and KX-95 is much larger, ranging from 1450 to 2200 yr with average 1σ uncertainties from 490 to 430 yr.

Moreover, for KX-93, a shift of ~1000 yr in the ages is observed between the mean values of the two successive series of dates produced in Groningen in 2002 and 2012. This cannot be explained by background problems, since anthracite is the blank used in all cases. The anthracite dates all are 45–50 ka BP. The cause for the shift is unknown and requires further investigation. In addition, for KX-93, the 2002 and 2012 series on identical samples (4b to 13) show some reproducible variations within a time range between 1450 and 950 yr. This suggests an influence of external factors, possibly related to natural variations in the atmospheric ^{14}C content. However, these variations are all within the 2σ uncertainty range.

Consequently, the ^{14}C fluctuations recorded at Kurtak on ring series of wood blocks may explain some puzzling results when dating small charcoal pieces from loess deposits assigned to the 30–34 ka BP time range. The ^{14}C dates for the period around 30 ka BP can be understood using 1σ "time ranges"; for dates older than 31 ka BP, we apparently should take 2σ "time ranges." For KX-93, both sets of dates fit within the time range of the Kurtak V Interstadial established by previous dates on wood material from subunit 4.2 (Figure 1; Haesaerts et al. 2005, 2010).

Concerning the large discrepancies in some dates occasionally encountered in some loess sequences discussed by Haesaerts et al. (2005) and Damblon and Haesaerts (2007), some may be outliers recorded in the Kurtak wood material, such as samples 4 and 8 on KX-84 and samples 7 and 15 on KX-93. In any case, the coherence of the series of ^{14}C dates needs to be evaluated with regard to the pedosedimentary and chronostratigraphic background of the record to be dated (Haesaerts et al. 2010).

ACKNOWLEDGMENTS

The authors acknowledge D Houbrechts and E Delye (ULg, Dendrochronology) for their contribution in the tree-ring count and measurement. They also thank E Dermience (RBINS, Palaeontology) for technical support and B Miller (ULg, Prehistory) for reviewing the English text. They are also grateful to the reviewers who contributed to improve the manuscript.

REFERENCES

Beck JW, Richards DA, Edward RL, Silverman BW, Smart PL, Donahue DJ, Herrera-Osterheld S, Burr GS, Calsoyas L, Jull AJT, Biddulph D. 2001. Extremely large variations of atmospheric ^{14}C concentration during the last glacial period. *Science* 292(5526):2453–8.

Conard NJ, Bolus M. 2003. Radiocarbon dating the appearance of modern humans and timing of cultural innovations in Europe: new results and new challenges. *Journal of Human Evolution* 44(3):331–71.

Damblon F, Haesaerts P. 2007. Les datations ^{14}C à Mitoc-Malu Galben. In: Otte M, Chirica V, Haesaerts P, directors. *L'Aurignacien et le Gravettien de Mitoc-Malu Galben (Moldavie roumaine)*. ERAUL Liège 72. p 53–65.

Haesaerts P, Chekha P, Damblon F, Drozdov I, Orlova A, van der Plicht J. 2005. The loess-palaeosol succession of Kurtak (Yenisei basin, Siberia): a reference record for the Karga stage (MIS 3). *Quaternaire* 16(1):3–24.

Haesaerts P, Borziac I, Chekha VP, Chirica V, Damblon F, Drozdov NI, Orlova LA, Pirson S, van der Plicht J. 2009. Climatic signature and radiocarbon chronology of Middle and Late Pleniglacial loess from Eurasia: comparison with the marine and Greenland records. *Radiocarbon* 51(1):301–18.

Haesaerts P, Borziac I, Chekha VP, Chirica V, Drozdov NI, Koulakovska L, Orlova LA, van der Plicht J, Damblon F. 2010. Charcoal and wood remains for radiocarbon dating Upper Pleistocene loess sequences in Eastern Europe and Central Siberia. *Palaeogeography, Palaeoclimatology, Palaeoecology* 291(1–2):106–27.

Juday GP, Barber V, Duffy P, Linderholm H, Rupp S, Sparrow S, Vaganov E, Yarie J. 2012. Direct climate effects on tree growth in the Arctic. *International*

Arctic Science Committee. 25 p. http://www.eoearth.org/view/article/151734/.

Kitagawa H, van der Plicht J. 2000. Atmospheric radiocarbon calibration beyond 11,900 cal BP from Lake Suigetsu laminated sediments. *Radiocarbon* 42(3):369–80.

Magda VN, Zelenova AV. 2002. Radial growth of pine as an indicator of atmosphere humidity in Minusinsk hollow. *Izvestiya Russkogo Geograficheskogo Obshchestva* 134(1):73–8. In Russian.

Schweingruber FH. 1996. *Tree Rings and Environment. Dendroecology*. Bern: Paul Haupt.

Turney CSM, Fifield LK, Palmer JG, Hogg AG, Baillie MGL, Galbraith R, Ogden J, Lorrey A, Tims SG. 2007. Towards a radiocarbon calibration for Oxygen Isotope Stage 3 using New Zealand kauri (*Agathis australis*). *Radiocarbon* 49(2):447–57.

Turney CSM, Fifield LK, Hogg AG, Palmer JG, Hughen K, Baillie MGL, Galbraith R, Ogden J, Lorrey A, Tims SG, Jones RT. 2010. The potential of New Zealand kauri (*Agathis australis*) for testing the synchronicity of abrupt climate change during the Last Glacial Interval (60,000–11,700 years ago). *Quaternary Science Reviews* 29(27–28):3677–82.

van der Plicht J, Imamura M, Sakamoto M. 2012. Dating of Late Pleistocene tree-ring series from Japan. *Radiocarbon* 54(3–4):625–33.

Voelker AHL, Grootes PM, Nadeau M-J, Sarnthein M. 2000. Radiocarbon levels in the Iceland Sea from 25–53 kyr and their link to the Earth's magnetic field intensity. *Radiocarbon* 42(3):437–52.

https://doi.org/10.2458/56.17500 Published online by Cambridge University Press