Chapter 5

RADIOCARBON, THE CALIBRATION CURVE AND SCYTHIAN CHRONOLOGY

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ABSTRACT

Interpretation of Radiocarbon dates can be rather complex. For example, variations in the natural ^{14}C content cause the ^{14}C clock rate to vary throughout time, causing the need for calibration of the ^{14}C timescale. For the Scythian epoch, there is a problematic range in the ^{14}C calibration curve. Radiocarbon dates of around 2450 BP always calibrate to ca. 800-400 BC, no matter the measurement precision.
In order to establish reliable chronologies, both state-of-the-art scientific and archaeological dating methods need to be employed. This includes high precision ^{14}C dating and AMS, enabling dating of small samples such as from museum collections or other precious materials.

Key words: chronology, radiocarbon, calibration curve, archaeology, Scythian, environment

INTRODUCTION

Radiocarbon (^{14}C) dating is the most common scientific dating method, as opposed to archaeological dating based on e.g. pottery or cultural association methods. It allows the measure of past time with a defined yardstick. This yardstick can be connected with (pre)historic ages by calibration of the Radiocarbon timescale (e.g., van der Plicht and Bruins, 2001).
The method enables chronological comparison of different areas at an excavation site and also between sites and regions, independent of cultural deliberations. This is essential for proper interpretation of archaeological layers and association with data from other fields. While the method is basically simple, it is complex in detail and errors in matters such as sampling and association are easily made. Therefore, quality control is necessary to build up a reliable ^{14}C chronology. Important aspects of quality control involves regular laboratory intercomparisons, multiple measurements of samples, issues such as conventional versus AMS, sample

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selection, association, and others (van Strijdonck et al., 1998; Boaretto et al., 2003).

The chronology of Scythian cultures during the first millennium BC is very important. The beginning of the Scythian epoch in Eurasia is not yet well established, mainly because for European Scythian cultures this is based on archaeological reasoning (typological comparisons) and historical sources, while for Asian Scythian cultures radiocarbon dating has been used (Alekseev, 2001).

Only recently ^{14}C dates became available for the European Scythian monuments. In addition, cooperation with western laboratories introduced the AMS dating technique in Russia, enabling the dating of small samples from museum collections or intrinsically small samples.

Issues of quality control and proper calibration of the ^{14}C dates yields a better understanding of changes in migration and environment during the Scythian epoch. Unfortunately, the ^{14}C dating method is hampered for a crucial timerange during the Scythian epoch because the calibration curve shows a very large plateau (the "Hallstatt" plateau; Becker and Kromer, 1993) from ca. 800-400 BC (at 2450 BP). Just before and after the plateau, calibration is accurate; during the plateau only techniques like wiggle matching yields useful calendar ages. This wiggle-match dating technique can be applied to well defined stratigraphical sequences, tree rings and organic deposits. Environmental changes can be dated accurately, enabling teleconnections with migrations caused by climate change (van Geel et al., this conference).

THE ^{14}C DATING METHOD

Definitions

The naturally occurring isotope ^{14}C (Radiocarbon) is continuously produced in the earth's atmosphere by cosmic radiation. Radiocarbon is radioactive and decays with a half life of 5730 ± 40 years (Godwin, 1962). A stationary state of production, distribution between the main carbon reservoirs (atmosphere, ocean and biosphere) and decay results in a more or less constant ^{14}C concentration in atmospheric CO_2 (Mook and Waterbolk, 1985; Mook and Streurman, 1983).

However, it has been known for some time that the ^{14}C concentration of atmospheric CO_2 has not always been the same in the past. In tree rings, natural variations of the atmospheric $^{14}CO_2$ abundance were discovered on a time scale of one decade to a few centuries (de Vries, 1958). Later it was discovered that these variations can be attributed to variations in solar activity (Stuiver, 1965), which in turn influence the production of ^{14}C in the atmosphere. Also changes of the geomagnetic field strength influence the production of ^{14}C in the atmosphere (Bucha, 1970). This is understood because both solar activity and geomagnetic field strength determine the amount of cosmic radiation impinging on the earth. In addition the

atmospheric $^{14}CO_2$ concentration also depends on exchange between the atmosphere and ocean.
Because of these variations in the natural ^{14}C concentration, the ^{14}C clock runs at a varying pace, different from real clocks: ^{14}C time ≠ historical time. Therefore, the ^{14}C timescale is *defined* and has to be *calibrated* to establish the relationship between ^{14}C time and historical time.
By definition, the ^{14}C timescale is expressed in BP = Before Present, where "Present" is the "standardyear" 1950 AD (Mook and van der Plicht, 1999). Radiocarbon measurements are always measured with respect to a standard (=Oxalic Acid with a radioactivity of 0.226 Bq/gC) which corresponds to that year. By convention, this definition includes correction for isotopic fractionation (to $^{13}\delta C$ = - 25‰) and uses the original value for the ^{14}C halflife (5568 years), used in the early days of the ^{14}C dating method (Libby, 1955).
The correction for isotopic fractionation is essential when dating materials with $\delta^{13}C$ strongly deviating from the standard value –25‰. Since 1‰ in $\delta^{13}C$ corresponds to 16 BP, this correction is also crucial when performing "high precision" dating with errors (1σ) down to 15 BP.

Calibration

Calibration involves measuring samples by both the ^{14}C method (in BP) and another method. Ideally this other method has to be independent from ^{14}C, yielding absolute dates (in AD/BC), and the samples have to be terrestrial (atmospheric).
The most ideal samples for calibration are tree rings, because they can be dated absolutely by means of dendrochronology. Following the early work of Suess et al. (Suess, 1978), the ^{14}C community has issued special issues of the journal *Radiocarbon* with calibration curves based on dendrochronology. The latest and presently recommended calibration curve is INTCAL98 (Stuiver et al., 1998), to be updated and replaced by INTCAL04 (Reimer et al., 2002).
Because of the irregular shape of the calibration curve, the translation of a ^{14}C age (in BP) into a calendar age is not straightforward. Special calibration software has been developed, producing calibrated age ranges with 1σ or 2σ confidence intervals (Bronk Ramsey, 1998; van der Plicht, 1993; Stuiver and Reimer, 1993). Calibrated ages are reported in calBC or calAD (Mook, 1986). In addition, calBP is used, where calBP = 1950-calAD, i.e. calibrated or calendar years before1950 (="Present").
INTCAL04 is a calibration curve back to 26 ka calBP. The tree-ring part of INTCAL04 now extends back to ca. 12 ka calBP, well into the Younger Dryas. Back to 26 ka calBP, the curve is "marine derived". It is based on corals dated by both ^{14}C and U-series isotopes (Bard et al., 1998; Burr et al., 1998), and on ^{14}C dated foraminifera from a varved sediment from the Cariaco basin (Hughen et al., 1998).
The new INTCAL04 calibration curve is shown in Fig.1: the dendro-chronological part (both absolute and floating) and the marine derived part, separated at 12 ka calBP. The calibration dataset is decadal, i.e. has a

resolution of 10 calendar years. The uncertainties plotted are 1 σ.

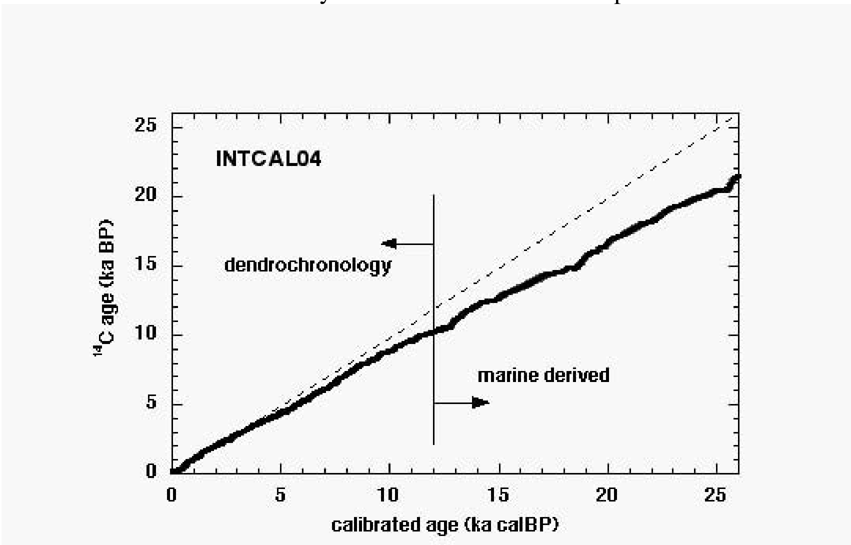

Figure1 The radiocarbon calibration dataset INTCAL04. The data are based on dendrochronology back to ca. 12.000 years ago; beyond, the data are based on paired ^{14}C / U-series datings of Pacific corals, and foraminifera dated with high resolution from the Cariaco basin laminated marine core.

When zooming in on details, wiggles are readily visible showing the "elastic" nature of ^{14}C time, such as is shown in Fig.2 (a and b). Fig.2a shows the INTCAL04 calibration curve for the first millennium BC. The Hallstatt plateau is apparent between 800 and 400 calBC. In $\Delta^{14}C$ space, the same data are plotted in Fig.2b. $\Delta^{14}C$ denotes the atmospheric ^{14}C content expressed as the per mil deviation of the ^{14}C content of the oxalic acid standard, after correction for radioactive decay and fractionation (Mook and van der Plicht, 1999).

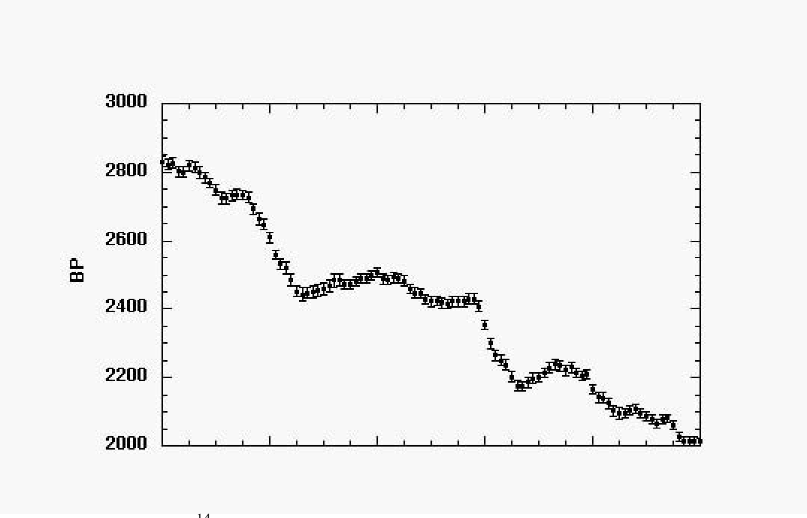

Figure 2.a. Part of the ^{14}C calibration curve INTCAL04: the first millennium BC. Plotted as radiocarbon ages in BP vs. calBC.

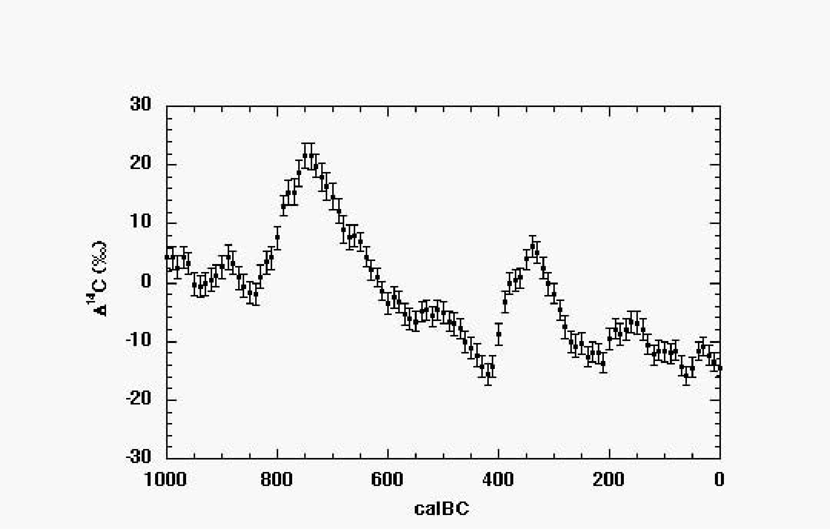

Figure 2.b. Part of the ^{14}C calibration curve INTCAL04: the first millennium BC. Plotted as $\Delta^{14}C$ vs. calBC.

Techniques

Radiocarbon measurements can be performed by applying two intrinsically different techniques: radiometry and mass spectrometry.

Radiometry is the conventional method, measuring the radioactivity by either Proportional Counters or by Liquid Scintillators. The technique of AMS (Accelerator Mass Spectrometry) is based on measuring the $^{14}C/^{12}C$ abundance ratio. Determining the ^{14}C concentration rather than the decay comes to measuring a system 6 orders of magnitude larger. This implies that much less carbon is required for obtaining the same precision, i.e. a few milligrams instead of grams. In addition the measuring time is much shorter. This allows ^{14}C dating of selected materials such as specific plant remains, museum collections, intrinsically small samples etc.
It is noted that the conventions and definitions for ^{14}C dating (like the BP timescale, standards and $\delta^{13}C$ fractionation correction) apply to both AMS and conventional techniques.
More technical details can be found in the proceedings of series of conferences – ^{14}C and Archaeology, Radiocarbon and AMS. For Groningen, we refer to Mook and Streurman, 1983 (conventional); Aerts et al., 2001 (AMS sample handling) van der Plicht et al., 2000 (AMS accelerator).

Quality control

Quality assurance is essential for ^{14}C dating. Over the years, this issue has been discussed in great detail. For example, van Strydonck et al. (1999) define a "^{14}C event" as "the isolation of some carbon containing substance from the reservoir(s) from which its carbon was obtained"; i.e., the ^{14}C event starts the radiocarbon clock. This is usually the "death" of some organism. Questions to be answered are: what is the ^{14}C event for each the materials to be dated; how is each ^{14}C event associated with the human event; what is exactly the archaeological or human event of interest; can ^{14}C provide the age information required; and, finally, does the material for which the ^{14}C event has been identified meet the requirements for a conventional ^{14}C age ?
Such questions can be translated to issues "in the field" and "in the laboratory". In the field, the most important issues are association and / or stratigraphy, contamination, preservation, sample selection. In the laboratory, quality amounts to control of standards, background, corrections for fractionation, calibration, precision, comparability and intercomparison.
The intercomparison issue was part of the FIRI program. The FIRI (Fourth International Radiocarbon Intercomparison) was performed with the following aims:
- evaluation of the comparability of routine analysis of both AMS and conventional ^{14}C laboratories;
- quantification of the extent and sources for any variation;
- investigation of the effects of sample size, precision, and pretreatment on the results. The results are reported by Boaretto et al., 2003 and Scott, 2003.

Samples to be dated by AMS need to be treated with particular caution, since the smaller the sample the greater the effect of any contaminant present (Lanting and van der Plicht, 1993/94). Contamination of samples

with older or younger material can occur in the field and/or while taking and handling the samples in the laboratory.
This has consequences for the strategy for choice of ^{14}C dating method - “AMS versus Conventional” . The specific advantages of AMS are clearly demonstrated. But if sufficient material is available, samples can be more cheaply and at least as accurately be dated by conventional means. The possibility of disappointment in the form of an unexpected date is great when isolated small fragments of charcoal are used, and certainly if these have not been found in a clearly defined feature or in close association.
In addition, high precision measurements (≤ 2 ‰ precision) are thus far only demonstrated by conventional methods, using large (also by conventional standards) amounts of material.
An example of a state-of-the-art application of ^{14}C dating to archaeology is shown by Bruins et al. (2003), employing both conventional and AMS techniques. Well suited datable material was selected (short lived grains) in well stratified contexts. Large quantities of single year material were available for high precision conventional dating; smaller samples had to be dated by AMS but this was done in multiple measurements in order to increase precision.

RESULTS

The Groningen ^{14}C datelist

In Table 1, ^{14}C dates measured by both Groningen laboratories (conventional: GrN and AMS: GrA) connected with the “Scythian projects” are listed. Reported are the measured ^{14}C dates in BP, stable isotope ratios $\delta^{13}C$ in ‰, and the Carbon content (in %). The latter ($\delta^{13}C$ and %C) are indicators for quality of the sample material.

Table 1. List of the ^{14}C dates of the Scythian monuments measured by the Groningen Laboratory

lab nr.	site	mate-rial	^{14}C age, BP±1σ	pre-treat ment	$\delta^{13}C$ ‰	con-tent C %	calBC, 1σ range
GrA-21532	Arzhan-2, grave 13a	cloth	2240±45	AAA	-19.79	40.7	380-350, 315-205
GrA-21533	Arzhan-2, grave 13a	fur	2555±45	AAA	-19.95	44.1	800-760, 680-560
GrA-21534	Arzhan-2, grave 13b	leather	2330±45	AAA	-17.47	42.7	480-470, 410-360, 275-235
GrA-21341	Arzhan-2, grave 13b	felt	3010±70	AAA	-24.98	1.3	1375-1130
GrA-21526	Arzhan-2, grave 16	grass	2100±60	AAA	-24.50	18.8	200-45
GrA-21527	Arzhan-2, grave 20	deposit	2500±50	AAA	-26.44	12.1	785-755, 720-520
GrA-18910	Arzhan-2, grave 5	grain	2520±40	AAA	n/a	n/a	790-760, 685-545
GrA-18931	Arzhan-2, grave 5	grain	2465±40	AAA	-27.30	44.7	760-415

GrA-18948	Arzhan-2, grave 5	grain, *duplo*	2485±40	AAA	-27.01	46.0	765-520
GrA-18932	Arzhan-2, grave 5	leather	2565±40	AAA	-20.75	41.6	800-760, 680-665, 615-565
GrA-18962	Arzhan-2, grave 5	leather *duplo*	2520±45	AAA	-20.90	39.3	790-755, 685-545
GrA-18920	Arzhan-2, grave 5	textile	2540±45	AAA	-20.17	40.8	795-760, 685-545
GrA-18939	Arzhan-2, grave 5	textile *duplo*	2455±45	alkali fraction	-21.57	39.3	760-640, 590-410
GrA-18938	Arzhan-2, grave 5	soil	2535±45	AAA	-26.50	43.9	795-760, 685-545
GrA-18935	Arzhan-2, grave 5	wood	2470±40	AAA	-27.86	62.9	760-515, 460-415
GrA-18949	Arzhan-2, grave 5	grain	2565±40	AAA	-9.66	40.1	800-760, 680-665, 615-565
GrA-18928	Arzhan-2, grave 5	bone	2590±80	none	-26.40	0.9	835-755, 685-540
GrA-18941	Arzhan-2, grave 5	bone *duplo*	1940±50	A	-22.73	0.2	5-125 calAD
GrA-19036	Arzhan-2, grave 5	char-coal	2740±45	AAA	-23.95	39.6	915-830
GrA-19216	Arzhan-2, grave 5	cord	2515±45	AAA	-20.59	43.2	790-755, 685-540
GrA-19219	Arzhan-2, grave 5	grains	2480±45	AAA	-23.48	3.0	760-520
GrA-19028	Arzhan-2, grave 5	leather	2605±45	none	-21.24	39.5	825-765
GrA-19029	Arzhan-2, grave 5	leather *duplo*	2570±45	AAA	-20.46	44.9	805-760, 680-665, 630-565
GrA-19025	Arzhan-2, grave 2	wood	2475±45	none	-23.22	41.9	760-520, 460-455
GrA-19026	Arzhan-2, grave 2	wood *duplo*	2490±45	AAA	-23.22	46.1	765-520
GrA-19220	Novozaved ennoe-II, grave 7	wood	2615±45	AAA	n/a	n/a	830-770
GrA-19221	Novozaved ennoe-II, grave 16	wood	2410±45	AAA	n/a	n/a	755-720, 540-405
GrA-10203	Chertom-lyk	wood (arrow point)	2320±50	AAA	-23.87	42.5	410-355, 285-215
GrA-10204	Chertom-lyk	wood (arrow point)	2350±50	AAA	-24.31	40.6	515-365, 270-265
GrA-10059	Chertom-lyk	wood (arrow point)	2180±40	AAA	-22.30	40.7	355-290, 260-175
GrA-10060	Solokha, grave 4	wood	2325±40	AAA	-22.40	41.4	405-365, 270-265
GrA-10159	Solokha, grave 5	wood	2270±50	AAA	-23.10	42.8	395-355, 290-210
GrA-10160	Solokha, grave 6	wood	2350±50	AAA	-23.64	43.3	515-265
GrA-	Oguz,	grass	2170±40	AAA	-29.51	67.0	355-295,

10163	grave 9						255-165
GrA-10164	Pastak, grave 10	wood	2330±50	AAA	-24.44	47.3	495-355, 285-235
GrA-12895	Gumarovo	deposit	2500±70	AAA	-21.94	9.9	785-520
GrA-16829	Gumarovo	leather	2500±50	AAA	-21.41	28.9	785-520
GrA-16831	Temir	wood	2250±50	AAA	-25.54	64.8	385-355, 315-205
GrA-16832	Aksenovka	wood	2660±50	AAA	-24.26	53.5	895-880, 835-795
GrA-16833	Katkovo	bone (horse)	1245±45	Longin	-21.19	42.3	690-860 calAD
GrA-15907	Berel	felt	3870±60	AAA	-25.07	53.9	2460-2285, 2245-2210
GrA-15908	Berel	felt	2170±60	AAA	-20.60	43.8	355-115
GrA-15860	Filippovka	wood (base of gold deer)	2940±50	AAA	-25.02	29.5	1255-1050
GrA-15862	Filippovka	wood (base of gold deer)	2320±50	AAA	-24.33	31.2	410-355, 285-215
GrA-19222	Filippovka	wood (base of gold deer)	2275±45	AAA	n/a	n/a	395-355, 290-210
GrN-22497	Tuekta, T- 15	wood	2454±16	AAA	-24.16	50.7	755-690, 540-515, 460-415
GrN-22504	Tuekta, T- 22	wood	2463±16	AAA	-24.60	51.0	760-685, 660-645, 545-520
GrN-22511	Tuekta, T- 29	wood	2452±15	AAA	-24.63	53.1	755-700, 540-515, 465-415

The $\delta^{13}C$ values in the AMS datelist are measured by the Stable Isotope Mass Spectrometer, online connected to the automatic combustion system (Aerts-Bijma et al., 2001). The AMS ^{14}C dates however are corrected for isotopic fractionation using the $^{13}C/^{12}C$ ratios as measured by the AMS itself; these values are not very precise and not listed in the table.
The chemical pretreatment is in general AAA (Acid-Alkali-Acid) (Mook and Streurman, 1983). The temperatures and duration of the pretreatment varies, depending on matters like the delicacy of the sample material. For bone, the datable fraction is collagen, extracted according to the Longin recipe (Mook and Streurman, 1983).
For Arzhan-2, most dates are acceptable as being "Scythian". They scatter around 2500 BP with some exceptions. Some more results are available from the laboratories in Tucson (AA) and Uppsala (Ua), with in general similar ^{14}C dates. All together the averaged date is ca. 2515 BP. Unfortunately, this corresponds with the Hallstatt plateau so that the

calibrated age range is very large (ca. 800-550 calBC). From the archaeological point of view, the Arzhan-2 monument should date to the 6^{th}-7^{th} century BC.
A peculiar result, not on the ^{14}C date but concerning the stable isotope ^{13}C, is the $\delta^{13}C$ value of grains from grave 5 (GrA-18949). The $\delta^{13}C$ = -9.66 ‰, measured in duplo; the grains therefore must originate from C4 type plant material, most likely millet (*Panicum miliaceum*). This observation also stresses the importance of correction of ^{14}C dates for isotopic fractionation; when we would not correct, the error in Radiocarbon years would be 240 BP.

There are a few problematic dates, which can readily be seen from the table. The problems arise from the poor quality of the sample material. For example, GrA- 21341 (felt from grave 13b, Arzhan-2) shows a very old date. However the organic carbon content of the sample was very low, too low to consider the date reliable. The material likely consisted mostly of soil components, which is also indicated by the $\delta^{13}C$ value.
The bone from Arzhan-2, grave 5 is also not datable according to our quality standards. The organic carbon content is extremely low, and the $\delta^{13}C$ value deviating. The bone was very delicate, so it was decided to date without any pretreatment (GrA-18928). The resulting ^{14}C date does look reasonable; however, a duplicate analysis with partly preatreatment (A only; GrA-18941) makes the bone too young.
For a sample of grains (Arzhan-2, grave 5), the carbon content is also much too low (GrA-19219). Nevertheless, both the ^{14}C date and the $\delta^{13}C$ value are as expected; apparently the pretreatment, removing contaminants, was effective for this material.
Textile is often a difficult material to date what can be caused by various contaminations by penetrated preservatives. In addition, the dated organic material may not be homogeneously distributed in the textile as well. An example of a textile date that does yield a good result, is from Arzhan-2 grave 5. The AAA treated sample (GrA-18920) yields a reasonable good ^{14}C date; the alkaline fraction of the same material (GrA-18939) gives the same date, within error.
A peculiar observation is the relatively young date for the grass sample GrA-21526. The grass was found in the mouth of one of the horses from the collective horse grave no.16. A preliminary date on bone from one of the horses (measured in St. Petersburg) also is young. This will be investigated in more detail in the near future.

The calibrated ages in the table are reported in calBC. They are calculated by the Groningen calibration program (van der Plicht, 1993) using the intcal98 dataset (Stuiver et al., 1998), and are rounded off to the nearest 5 years.
A more complete datelist (including measurements by other laboratories: Russian conventional, and Tucson, AA plus Uppsala, Ua for AMS) can be found in Alekseev et al. (2001, 2002).

THE 1ST MILLENIUM BC

During the 1st millennium BC, the radiocarbon calibration curve shows a large “plateau” between 800 and 400 calBC, the Hallstatt plateau (fig.2a). Unfortunatly, this coincides for a large part with the Scythian epoch. The Scythian archaeological chronology (Alekseev, 2001) is based on typological dating of artifacts, dating of imported Greek ceramic and amphorae, historical-biographical writings, and stratigraphy. The following periods are recognised:
1st period: 9th – 7th century, pre-Scythian & initial Scythian epoch;
2nd period: 7th – 6th century, Early Scythian epoch;
3rd period: 5th – 4th century, Classical Scythian epoch.
Isolated ^{14}C dates – even when measured with high precision – around 2500 BP do not provide accurate historical information. On the other hand, dates which fall on the steep slopes on either side of the plateau can be calibrated very accurately.
An example of the latter is the ^{14}C dating of Solokha (Alekseev, 2002).
The classical Scythian royal tomb Solokha is one of the greatest Scythian barrows in the Northen Black Sea region. The tomb construction occurred during a rather short period of time. According to achaeological data, this barrow dates to 400-375 BC. Eleven ^{14}C dates are available by two laboratories - 3 AMS dates (Groningen, GrA) and 8 conventional dates (Kiev, Ki). Most samples were wood from a sword, but also grass rope and leather has been dated (see datelist). All the dates show very good overlapping results, averaging to 2333 ± 15 BP. This calibrates to 400-395 calBC (1σ) and 405-390 calBC (2σ), which is in excellent agreement with archaeological reasoning. In terms of calibration, this can be considered “good luck”: the ^{14}C date (averaged, a high precision result) calibrates very accurately because it falls on the steep slope of the calibration curve, directly following the Hallstatt plateau.
An example which can be considered as “bad luck” is the ^{14}C dating of the Tuekta monument. The Tuekta monument is located in the Altai region of Southern Siberia.Wood from the barrow has been dated by conventional means in St.Petersburg (Le) and Groningen (GrN), the latter with high precision. A representative result is 2460 ± 15 BP, exactly on the Hallstatt plateau. Calibration of such a date, whether measured with high precision or not, will always result in a calibrated age range between 760 and 400 calBC, almost 4 centuries long – see Fig.3.

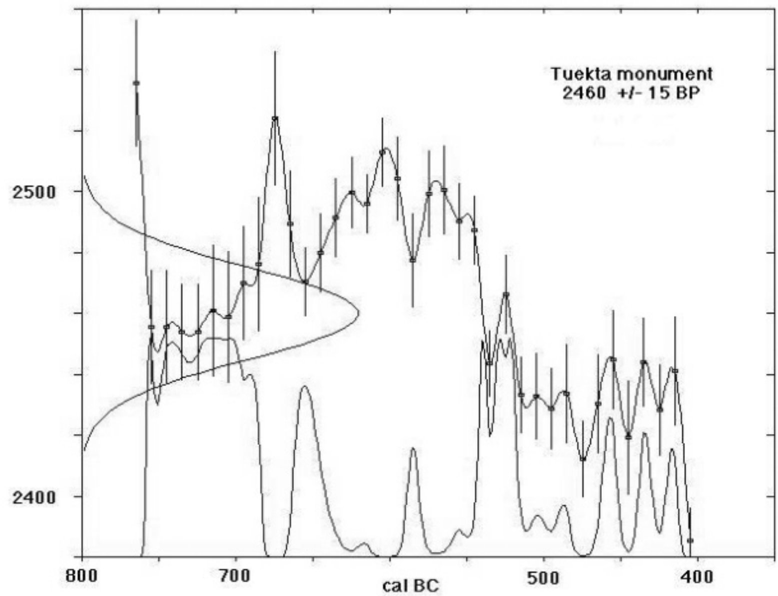

Figure 3. Calibration at the Hallstatt plateau: 2460 ± 15 BP.
The graph shows the calibration curve (spline function through the data), the Gaussian probability distribution corresponding to the ^{14}C age 2460 ± 15 BP along the vertical axis, and the calibrated calendar age probability distribution along the horizontal axis.

Nevertheless, techniques like Wiggle Matching can enhance the application of ^{14}C dating during this era, as will be discussed below.

Wiggle Matching: archaeology

The wiggles which complicate calibration of a ^{14}C date, can be used to our advantage by considering a series of ^{14}C dates from an organic sample that has accumulated through time. For example, a series of ^{14}C dates whose real spacing in time is known, such as dates for every n^{th} annual ring of an (undated) piece of wood. Such a series of ^{14}C dates constitutes a short section of the calibration curve, and can be matched against the full calibration curve. Depending on the characteristics of the wiggles in the calibration curve at the appropriate interval, a series of ^{14}C dates can be matched to within a few years on the calendar axis (see e.g. van der Plicht et al., 1995; van der Plicht and McCormac, 1995).
Wood samples can be used in a straightforward way for wiggle matching, because they show a constant growth (1 annual ring per calendar year).

A first attempt to apply WMD for Scythian chronology is the Tuekta monument. We dated wood from tree D24 from the barrow Tuekta-1. This tree constituted 30 rings. Only 3 contained sufficient wood (≈ 20 gram or more) for the large Groningen counter – ring numbers 15, 22 and 29 (see

datelist). The samples are dated around 2460 BP with a precision (1σ) of 15-16 BP. As will be obvious from fig.3, even WMD for this dataset results in a large calibrated age range of almost 4 centuries.
However, using these dates in a special statistical model does provide a match with the calibration curve, within a certain error. Floating trees were dated in St.Petersburg (Le) for Tuekta-1 and other Scythian barrows, Arzhan-1 (Tuva, Central Asia) and Pazyryk (Altai region, Southern Siberia). A total of 11 dates (including the 3 high precision GrN dates) for Tuekta, combined with 8 dates from Arzhan and 10 from Pazyryk together provide a most likely chronology (Zaitseva et al. 1998): Arzhan-1: ca. 810 calBC, in accordance with archaeology; Tuekta-1: ca. 655 calBC, about 1 century older than previously believed; and Pazyryk: ca. 380 calBC, in accordance with archaeology.

Wiggle Match Dating: the environment

Apart from wood samples where WMD is relatively straightforward (growth = 1 ring per calendar year), the technique can also be used with peat deposits of which the deposition rate can be estimated (van Geel and Mook, 1989). In this case, the "growth" is the peat accumulation rate (in cm per calendar year). The "floating" stratigraphic depth series of peat chronology AMS dates can not only be moved along the calendar axis (such as with treerings), but also stretched or compressed to match the wiggles in the calibration curve. The stretching and compressing corresponds to higher and lower peat accumulation rates, respectively. The simulated peat accumulation rate will apply to the complete series of dates with the assumption that these rates have remained constant over the dated depth interval. Wiggle Match Dating (WMD) on peat requires ^{14}C dating by AMS because selected plant materials (pollen or macrofossils) need to be used (e.g. Kilian et al., 2000; Speranza et al., 2000; Blaauw et al., 2003; Mauquoy et al., 2004).
In a study of AMS - WMD of selected macrofossils from organic deposits at ca. 850 calBC (the SubBoreal - SubAtlantic climatic transition), van Geel et al. (1998) found based on palaeoecological, archaeological and geological evidence, the following phenomena:
i) in European raised bog deposits, the changing spectrum of peat forming mosses indicate a sudden change from relatively dry and warm to cool, moist climate;
ii) there was a fast and considerable rise of the groundwater table so that peat growth started in areas that were already marginal from a hydrological point of view;
iii) the rise of the groundwater table in low lying areas of the Netherlands resulted in the abandonment of settlement sites;
iv) the contemporaneous earliest human colonization of newly emerged marshes (starting living on mounds).
Later, WMD on peat deposits showed similar phenomena during the Little Ice Age (LIA) (Mauquoy et al, 2002) and the PreBoreal Oscillation (PBO). The LIA is of particular interest because of the absence of sunspots during

the Maunder minimum; the PBO era is linked with ice cores ($\delta^{18}O$ climate proxy) and another cosmogenic isotope (solar activity proxy) ^{10}Be (van der Plicht et al., 2004).
In general, WMD of peat deposits show important teleconnections between climate cooling (more wet plant species), migrations, an increase in the cosmic ray flux (^{14}C and ^{10}Be), and reduced solar activity.
In central South Siberia, an acceleration of cultural development and population density of nomadic people took place after 850 BC. Van Geel et al (this conference) hypothesize that this is connected with an abrupt climatic shift towards increased humidity, after a decline in solar activity; newly available steppe areas allowed the expansion of horse-riding Scythian cultures, a stimulus for migration in western direction towards Europe.
Climate models are shifting now from a "less oceanocentric" orientation to allow solar forcing scenarios (Kirkby, 2001; Magny, 1993).
The ^{14}C excursions during the LIA, around 850 calBC, etc are part of the so-called Millennial Scale Oscillations, observed throughout the whole Holocene. The strongest evidence for solar forcing of climate change to date is observed by Bond et al. (2001). The North Atlantic climate (as observed in IRD, Ice Rafted Debris which is a cooling proxy) has warmed and cooled several times in the last 12000 years in step with waxing and waning of the sun (as observed in both cosmogenic isotope fluxes, ^{14}C and ^{10}Be). This is shown in fig.4.

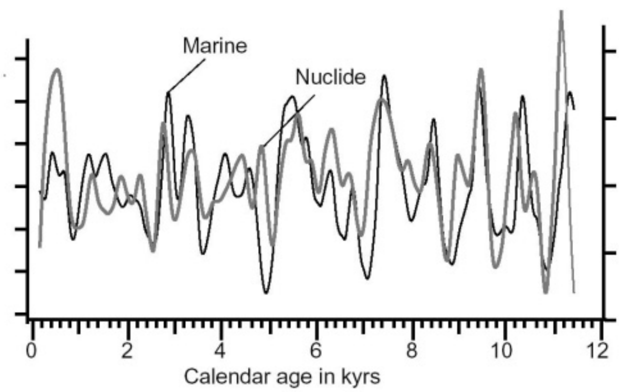

Figure 4. Synchroneity of fluctuations in Ice Rafted Debris and ^{14}C, suggesting that a varying sun can cause millennial climate change.

Apparently, the deep water formation does oscillate, but the timing is influenced by the inconstant sun (Kerr, 2001).

CONCLUSIONS

Methodological problems concerning the chronology of Eurasian Scythian cultures rely for a large part on scientific methods such as good quality ^{14}C dating.

A ^{14}C date (despite inherent limitations) does provide a universal physical measurement of time, independent of cultural-historical viewpoints and associative reasoning. Such information is of irreplacable value as both an independent and unifying data set in a variety of disciplines (like archaeology and environmental sciences).

Radiocarbon dates need to be calibrated in order to obtain historical (calendar) ages. Accurate decadal calibration curves are available for this purpose.

Unfortunately, the Scythian era coincides with a large “plateau” in the calibration curve between ca. 800 and 400 BC. Therefore, the best that ^{14}C has to offer needs to be applied in order to obtain useful chronological information.

Modern techniques like Wiggle Match Dating, statistical models, high precision (i.e. $\leq$ 2‰) conventional measurements, AMS analysis of small unique sample material, and quality control issues enable a better understanding of the origin, migration and disappearance of the Scythian cultures in Eurasia.

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