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A potential usefulness of radiocarbon dating for the authentication of Nicolaus Copernicus's grave[1]

Abstract

The authors analyse the potential usefulness of the method of radiocarbon dating to examine the grave of Nicolaus Copernicus, whose age is, in some sense, beyond the scope of the method which serves prehistoric archaeology rather than historic archaeology. The critical element in this case is the calibration curve, the shape of which makes it impossible to distinguish some "dates". A diagram was given indicating the age of the samples that can be distinguished using the method of ^{14}C.

Keywords: radiocarbon, ^{14}C, absolute dating, calibration curve, dating of the alleged grave of Nicolaus Copernicus.

1. Introduction

As it is apparent from the publications of the team of Professor Jerzy Gąssowski (cf. e.g. Gąssowski 2005; Gąssowski (ed.) 2005; Gąssowski (ed.) 2008), the radiocarbon dating method was not used in the search for the grave and the remains of Nicolaus Copernicus at the altar of St. Cross of the Archcathedral Basilica in Frombork. Therefore, in this article we recall the basic information about the method and point to some possibilities of its application in the particular case of study of the grave of Nicolaus Copernicus.

[1] The paper was peer-reviewed by Professor Marek Krąpiec, Habilitated Doctor in Technical Sciences (Laboratory of Dendrochronology and Malacology, Department of Environmental Analysis, Cartography and Economic Geology, Faculty of Geology, Geophysics and Environmental Protection, AGH University of Science and Technology, Kraków).

2. Formulation of the problem: the relevance of the results of the dating using carbon isotope ^{14}C

The radiocarbon absolute dating method, based on the carbon isotope ^{14}C is widely used in archaeology, since its range of application is up to 50,000 yr b2k (before 2000). A result of the dating is such an age range that the actual (real) age of the object falls within the given range with a probability of 0.95 or, depending on the epistemological preferences of a researcher, 0.68 (these numbers result from the range $\pm 2\sigma$ and $\pm 1\sigma$ of the normal distribution, with σ being the standard deviation).

It should be emphasized in this context that for a historical period not very remote from modern times (last 500 years), this method is less useful than for ancient times, because of the relatively large measurement uncertainty, i.e. the width of the age range mentioned. While, for example, 7060BC–6750BC date is acceptable and can bring a lot of information in archaeological research, the historical date 1490AD–1650AD can be useful only in an extreme situation of a lack of any *a priori* knowledge about the object. Nevertheless, the ^{14}C method is used for the dating of historical objects. Therefore it is necessary to examine the accuracy of this measurement method in more detail.

3. The calibration curve

The radiocarbon method is strongly dependent on the so-called calibration. In other words, what results from the physical fact that the ^{14}C concentration in the atmosphere in the past was not exactly constant is the necessity to use the so-called calibration curve in the measuring procedure (fig. 1). This is obtained by taking measurements of thousands of samples of otherwise known age, for example from dendrochronology (Reimer *et al.* 2009). As a result, this method is substantially free of the so-called systematic shift error – some nuances of the problem were noticed by Adam Walanus (2009).

Figure 2 shows a fragment of the calibration curve for the last six hundred years. Using this enlarged graph, it is easy to explain how the calibration procedure works.

The result of the measurement of the ^{14}C concentration in the sample is given on the vertical axis. As any typical measurement result, it is subject to normal distribution (cf. fig. 3).

A typical value may be 500±30 years BP (radiocarbon years *before present*). In this notation 500 years BP is called the radiocarbon date or, better, *radiocarbon determination,* whereas the value of 30 years is the error (uncertainty) of measurement. The value of the measurement error characterizes, in some sense, the

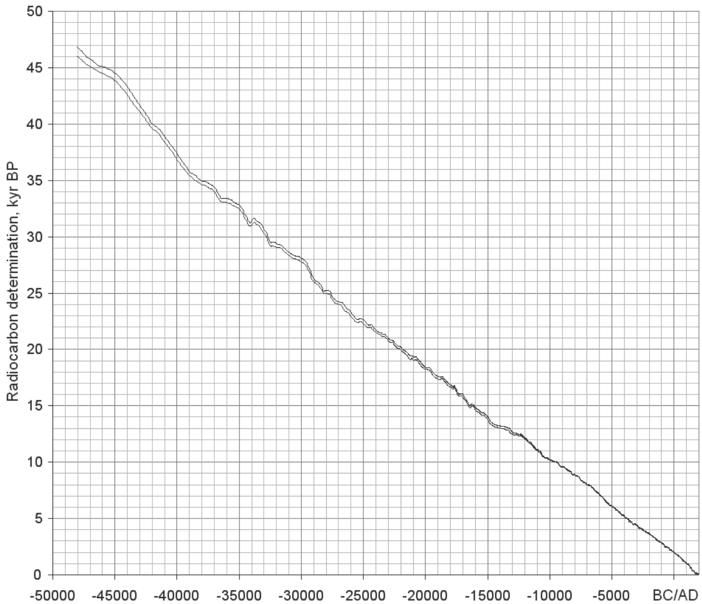

Fig. 1. The calibration curve of the radiocarbon dating method (IntCal09). The line is wiggled because of instabilities of the rate of production of ^{14}C as well as the atmosphere/ocean carbon exchange rate. The horizontal axis represents the age in years, while the vertical axis – the relative concentration of radiocarbon in the sample expressed in the so-called radiocarbon years (actually thousands of years; the abbreviation BP means before present, i.e. 1950AD).

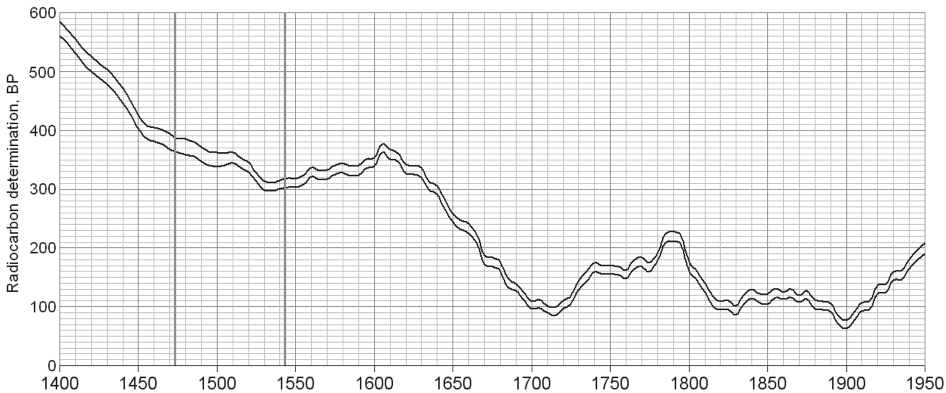

Fig. 2. The part of the radiocarbon calibration curve relevant to the subject. Two lines illustrate the precision of the curve itself. The precision, or rather the imprecision, or simply the measurement error of dates is in the range of 30–50 yr BP, as a rule. As a result, the samples of the age for which the expected "radiocarbon determinations" differ more than 60 or 100 years, would be distinguished. The dates of birth and death of Copernicus are marked. The graph axes – cf. the previous figure.

quality of measurement – to achieve a low measurement uncertainty we need to spend more money, because it requires a longer measurement. The error values of 20, 30 years may be obtained on special request. A typical value is ±40 years.

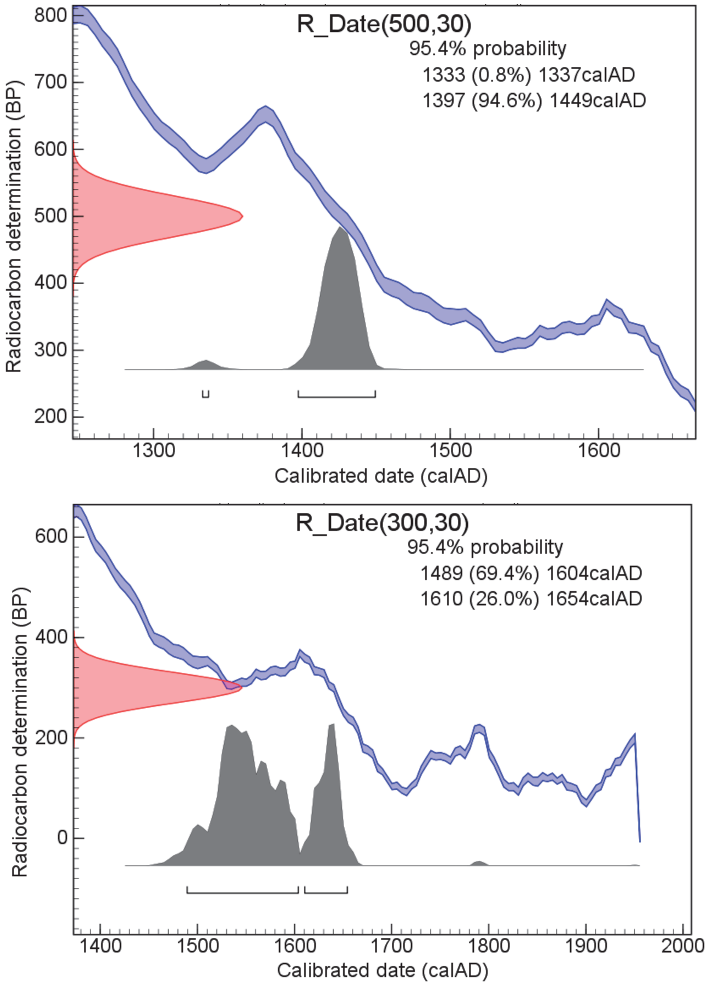

Fig. 3 a, b. Two examples of the dating results in its full, graphical form. The raw measurement result, the so-called “radiocarbon age”, is given in the upper part of the graph; it is 500±30 yr BP, and 300±30 yr BP respectively. This result, illustrated by the Gaussian curve on the vertical axis, is transformed by a calibration curve to form a complex curve placed on the axis of historical age, which is the final result of dating. The age ranges are also given with the respective probabilities (confidence levels) including the actual (unknown) age. For example, the entry “1610 (26.0%) 1654calAD” means that the 0.26 probability (confidence level) of the actual age of the sample lies within the range of 1610 to 1654 years. Graphs created with the OxCal4 program.

4. The usefulness of ^{14}C dating to verify archeological theses

Bearing in mind the size of the measurement uncertainty, whose value is placed on the above graphs on the vertical axis, and is usually ±40 years, and taking account of the measurement uncertainty of the calibration curve (on the charts it is a stripe, not an "exact" line), we can now proceed to formulate the answer whether the radiocarbon method can be applied to solve a given specific issue. For example, can it give an answer to the question whether a piece of wood interesting to us arose (i.e. a tree grew) in 1500 AD or rather much later?

As it is easily seen from the graph in fig. 2, for the following dates: 1500AD–1520AD, 1595AD–1602AD, 1610AD–1615AD, the *radiocarbon age* (*radiocarbon determination*) should be 350 BP. Consequently, radiocarbon dating cannot distinguish between each timber (bones, etc.) sample from these periods, because they have approximately the same concentration of ^{14}C.

At this point we need to draw attention to the possibility of application of a certain, specific approach to the radiocarbon dating of a combination of a few samples. It is called *wiggle matching*, i.e. fitting a group of dates to the bends of the calibration curve (Walanus, Goslar 2009). This is a procedure which gives a very precise date even in the range of the so-called *radiocarbon plateau* (flat sections of the calibration curve). However, this method requires samples "combined" in time. In practice, this applies almost exclusively to wood samples in which we can count annual growth rings. If we have a beam composed of 50 growth rings, it may appear that it is insufficient to date the tree using the dendrochronological method, but may be sufficient to use wiggle matching. A couple of dates obtained from the extreme growth rings of the beam must match the bends of the calibration curve, which in a favourable situation can seriously reduce the uncertainty of measurement. To summarize, the graph in fig. 2 can be used as follows: if for two historical dates (AD, horizontal axis) the values read from the calibration curve on the vertical axis (BP) are similar, the radiocarbon method will not be able to determine which of the two dates is true for a given sample; if, instead, for two putative AD dates we obtain quite different values of BP, it is worth investing in the dating. An example of the latter case may be the question whether the given sample comes from the lifetime of Copernicus, or is later than 1650 AD.

The issue considered concerns the comparison of two historical dates (in terms of radiocarbon). Hence, a graph in which historical dates (AD) are on both axes should be of use. This graph is proposed on fig. 4, and it is read as follows: If the point specified by two hypothetical historical dates (the age of the "real" object and the age of the supposed forgery) is white, a measurement of ^{14}C will not distinguish between these two radiocarbon dates (since samples have the same amount of ^{14}C), whereas the dark colour indicates that such a measurement

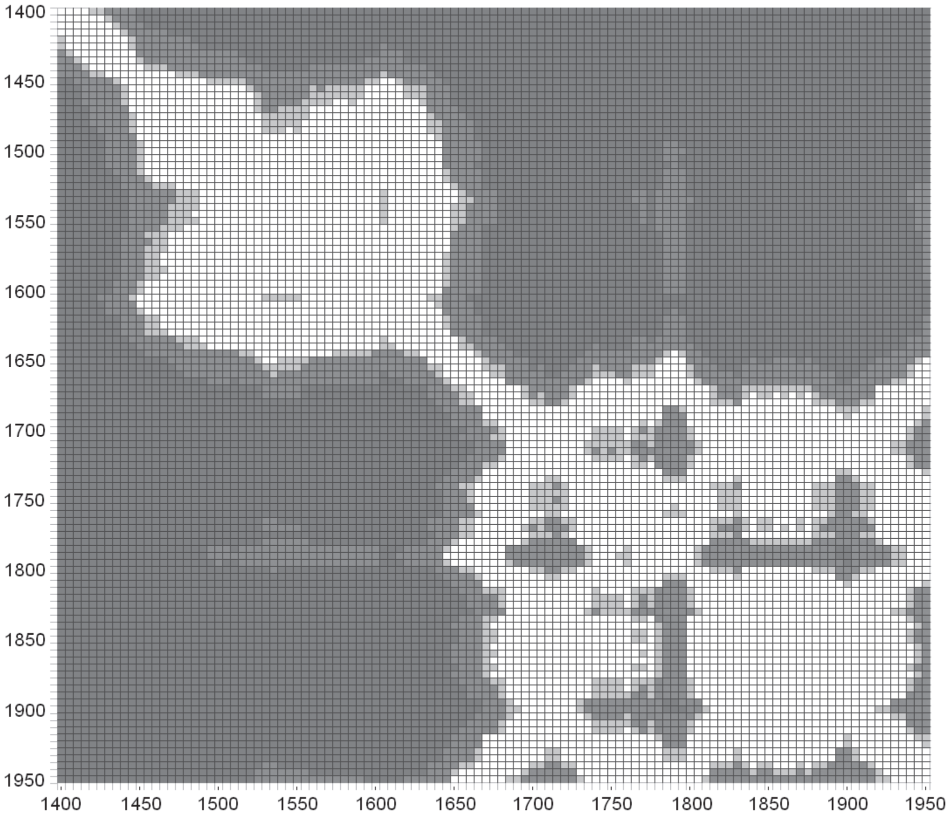

Fig. 4. The array of p-values (≈significance levels) expected when two samples of a given, expected true age are compared. The white area around the diagonal indicates indistinguishable ages. The darkest area indicates the pair of dates that certainly would give different results in the measurement of ^{14}C. Intermediate gray is for α=0.01; 0.05 and 0.001. The assumed radiocarbon determination error is σ=30 yr.

will be successful with a high probability. The intermediate shades of gray are defined by the respective degrees of the expected certainty. Three boundaries between different shades of gray correspond to the three levels of significance: α = 0.1, 0.05, 0.001, of which the last (smallest) one corresponds to the darkest colour. (The degree of certainty or the confidence level is associated with the level of significance in such a manner that the sum of their values is equal to 1).

Another issue is the dating of samples that can be called contemporary, i.e. younger than 1950 AD. Due to the nuclear weapons tests conducted after this year, the level of ^{14}C in the atmosphere doubled. In consequence, the dating of samples from that time leaves no doubt as to their age. This is the so-called bomb effect (cf., e.g., Walanus, Goslar 2009).

As far as the possibility of using the radiocarbon method is concerned, we have to mention the type and the quantity of the material suitable for the dating. As ^{14}C is a carbon isotope, the sample must include this element in sufficient amount. For this and other reasons, the pieces of wood are the most useful. Before asking a question about the necessary weight of the sample, we should note that there are two completely different methods of measuring ^{14}C in parallel use: the older Scintillation Method and the new method of AMS, i.e. Accelerator Mass Spectrometry. They have different measuring sensitivities. The former requires grams of carbon, the latter – milligrams. This is the principal difference between them. Fortunately, the price of accelerator dating is not a thousand times higher. It is obvious that it is much easier to acquire a small sample for measurement. Therefore, only after AMS had been more widely used, was the Shroud of Turin dated (cf. Damon *et al.* 1989). In Poland, Poznań Radiocarbon Laboratory, which uses the method of accelerator mass spectrometry, recommends the following masses of samples: charcoal: 2–5 mg, peat: 5–10 mg, wood: 5–10 mg, shells: 20–50 mg, speleothems and other carbonate formations: 20–50 mg, bones: 1–5 g (see Poznańskie Laboratorium Radiowęglowe 2010). In contrast, Absolute Dating Laboratory in Skała (Poland), which uses the scintillation method, recommends larger samples: wood: 10–50 g, a minimum of 2–5 g; charcoal: 5–30 g, a minimum of 1–3 g; peat: 50–100 g, a minimum of 2 g; bone: 200–300 g, a minimum of 30 g (see Laboratorium Datowań Bezwzględnych w Skale 2010).

The final remark regarding the moment in time that is the result of the dating with the radiocarbon method. The date indicates the time when the plant tissue collected "fresh" carbon from the atmosphere (CO_2). A further circulation of the carbon (eaten by the animals in the form of grass, etc.) takes place almost instantaneously. However, for example collagen in the bones circulates quite slowly, which may have some significance for dating. The most unfavourable situation regards aquatic plants: radiocarbon dating of such samples should be avoided as they consume carbon from water, which at least partly is of mineral origin, and as far as ^{14}C is concerned, it is very old and no longer contains the isotope. Wood is a very good material for dating, but we must remember that 1) in the construction under study, a very old (already then) piece of wood could have been used, and 2) even in the case of a freshly cut tree trunk, one could deal with its middle part, which, when it was cut, could already be one hundred years or more.

With regard to the grave of Nicolaus Copernicus, it also seems appropriate to elaborate on the issue of dating bones. In this case, we measure the age of collagen extracted from the bones. Collagen is a relatively stable substance which does not exchange carbon with its surroundings when the bone is buried in the ground.

However a laboratory preparation of bone is difficult and time-consuming. Very well-preserved not very old bones contain at least 20% of the initial amount of collagen, that is more than 40 mg of collagen per 1 g of bone. If the body was subjected to cremation or were burnt for other reasons, the bones contained no collagen and cannot be prepared with a standard technique. However, very often, a structural carbonate is retained in bones. This carbonate, deposited in the bone tissue throughout the life of the organism, contains the information about the true ^{14}C age (Walanus, Goslar 2009).

5. Conclusions

It seems that the radiocarbon dating of organic samples from the graves at the altar of St. Cross of the Archcathedral Basilica in Frombork may be an additional test of the relevance of the thesis about the discovery of the grave of Copernicus. The postulate for such additional tests was already reported (Kokowski 2008, 2009, 2010), as was also the suggestion that the team of Professor Jerzy Gąssowski determined precisely the methods of archaeological dating applied by them (Kokowski 2005b/2007).

The use of radiocarbon measurement method for the analysis of the remains attributed to Copernicus is relatively simple, since the remains are located in a secured coffin. In this context, however, we should emphasize that in the measurements of this type it is necessary to maintain great meticulousness in order to avoid being accused of failure to comply with elementary principles of performing this type of measurements.[2]

In addition, in order to increase the value of the accumulated empirical evidence, one should also test, using this measuring method, other archaeological objects discovered at the altar of St. Cross. It would, however, be much more organizationally difficult, since it would require a repetition of the archaeological work, because – as far as we know – these objects were placed in their original locations in the vicinity of the altar.

References

DAMON P.E., DONAHUE D.J., GORE B.H., HATHEWAY A.L., JULL A.J.T., LINICK T.W., SERCEL P.J., TOOLIN L.J., BRONK C.R., HALL E.T., HEDGES R.E.M., HOUSLEY R., LAW I.A., PERRY C., BONANI G., TRUMBORE S., WOELFLI W., AMBERS J.C., BOWMAN S.G.E., LEESE M.N., TITE M.S.

1989: *Radiocarbon dating of the Shroud of Turin*, “Nature”, vol. 337, no. 6208, pp. 611––615, 16 February; http://www.shroud.com/nature.htm.

[2] Cf. the problem of methodical shortcomings in the dating of the Turin Shroud using the method of mass spectrometry (Marion, Lucotte 2008, pp. 79–85).

GĄSSOWSKI Jerzy

2005: *Poszukiwanie grobu Kopernika*. In: O. Gingerich, J. MacLachlan, *Mikołaj Kopernik: gdy Ziemia stała się planetą*. Translated by Jarosław Włodarczyk, Preface by Jacek Jezierski, Afterword by Jerzy Gąssowski. Pułtusk: Wyższa Szkoła Humanistyczna im. Aleksandra Gieysztora, pp. 127–136.

GĄSSOWSKI Jerzy

(ed.) 2005 / (ed.) 2006: *Poszukiwanie grobu Mikołaja Kopernika*. "Castri Dominae Nostrae Letterae Annales" vol II. Pułtusk: Wyższa Szkoła Humanistyczna im. Aleksandra Gieysztora, Bałtycki Ośrodek Badawczy; (ed.) 2006a (English translation): *The Search for Nicolaus Copernicus's Tomb*.. Pułtusk: The Pułtusk Academy of Humanities, Institute of Anthropology and Archaeology; Fundacja Kronenberga, Citibank Handlowy.

2008: *Badania nad identyfikacją grobu Kopernika* / *The Search for identity of Copernicus Tomb*. Pułtusk: The Pułtusk Academy of Humanities, Institute of Anthropology and Archaeology; Fundacja Kronenberga przy Citi Handlowy.

KOKOWSKI Michał

2005a: *Poszukiwania grobu Kopernika. Refleksje advocati diaboli*, an on-line version: Part I; http://www.cyfronet.pl/~n1kokows/poszukiwania_cz_1_pl.html.

2005b: *Poszukiwania grobu Kopernika. Refleksje advocati diaboli*; an on-line version: Part II; http://www.cyfronet.pl/~n1kokows/poszukiwania_cz_2_pl.html.

2007: *Poszukiwania grobu Kopernika. Refleksje advocati diaboli*. Part 1–2, "Kwartalnik Historii Nauki i Techniki", vol. 52/1, pp. 121–131, 131–151.

2008: see Kostrzewa 2008.

2009: *Poszukiwania grobu Kopernika. Refleksje advocati diaboli*. Part 1–5. Presentation delivered at the "Symposium of the Copernicus Centre for Interdisciplinary Research" (Kraków, 20.03.2009).

2010: *Procedura identyfikacji szczątków nr 13/05 jako szczątków Kopernika w świetle racjonalności uzasadnienia i retoryki perswazji*. Presentation delivered at the conference "The Nicolaus Copernicus grave mystery. A dialogue of experts" (Kraków, 22–23 February 2010).

KOSTRZEWA Jarosław

2008: *Naukowcy szukają włosa Kopernika*, "Dziennik Polski", 6–7 December, no. 285 (19599), vol. LXIV, p. A4; http://www.dziennikpolski24.pl/pl/aktualnosci/kraj/888031-o-wlos-kopernika.html.

LABORATORIUM DATOWAŃ BEZWZGLĘDNYCH W SKALE

2010: *"Wymagane masy próbek"*; http://www.c14.pl/informacje-dla-zleceniodawcow (last accessed: 12.02.2010).

MARION André, LUCOTTE Gérard

2008: *Tunika z Argenteuil i Całun Turyński*. Kraków: Wydawnictwo M; http://books.google.pl/books?id=0s9LQkwCEWsC.

POZNANSKIE LABORATORIUM RADIOWĘGLOWE

2010: *"Rodzaje próbek"*; http://radiocarbon.pl/index.php?option=com_content&task=view&id=7&Itemid=7 (last accessed: 12.02.2010).

REIMER P.J., BAILLIE M.G.L., BARD E., BAYLISS A., BECK J.W., BLACKWELL P.G., BRONK RAMSEY C., BUCK C.E., BURR G.S., EDWARDS R.L., FRIEDRICH M., GROOTES P.M., GUILDERSON T.P., HAJDAS I., HEATON T.J., HOGG A.G., HUGHEN K.A., KAISER K.F., KROMER B., McCORMAC F.G., MANNING S.W., REIMER R.W., RICHARDS D.A., SOUTHON J.R., TALAMO S., TURNEY C.S.M., VAN DER PLICHT J., WEYHENMEYER C.E.

2009: *IntCal09 and Marine09 radiocarbon age calibration curves, 0–50,000 years cal BP*, "Radiocarbon", vol. 51(4), pp. 1111–1150.

WALANUS Adam

2009: *Systematic bias of radiocarbon method*, "Radiocarbon", vol. 51, pp. 433–436.

2010: *Tajemnice ^{14}C, czyli po co nam radiowęgiel*, "Archeologia Żywa", no. 1(47), pp. 44–48.

WALANUS Adam, GOSLAR Tadeusz

2009: *Datowanie radiowęglowe*. Kraków: Wydawnictwo AGH (pp. 147).