Polish Geological Institute Special Papers, 11 (2004): 109–112
Proceedings of the Conference “Rapid transgressions into semi-enclosed basins”

STATISTICAL ANALYSIS OF RADIOCARBON DATES AS A TOOL FOR RECONSTRUCTION OF THE ENVIRONMENTAL CHANGES

Danuta J. MICHCZYŃSKA[1], Adam MICHCZYŃSKI[1], Anna PAZDUR[1], Karol ROTNICKI [2]

Abstract. Statistical analysis of large sets of ^{14}C dates may be a source of information on global or regional environmental changes. Since the nineteen seventies, an analysis of the frequency distribution on a time scale of ^{14}C-dated samples has been carried out for several selected geographic regions. This paper presents basics of the applied method and examples of cumulative probability density functions constructed for ^{14}C dates of peat from territory of Poland. It is emphasised that preferential sampling plays an important role in such a type of analysis. The problem of absolute age determination has been discussed, too.

Key words: radiocarbon, peat, statistical analysis, environmental change.

INTRODUCTION

During a few decades of radiocarbon dating development, this method evolved into an independent scientific discipline. The radiocarbon dating technique has become a standard tool for the Quaternary geologists and archaeologists, as well as for scientists involved in studies of environmental processes. For example: at present, the chronostratigraphy of the middle and upper Vistulian and Holocene is based on conventional ^{14}C dates. Environmental changes in the past, reconstructed from pollen diagrams, are based on radiocarbon dating of peat-bog profiles (Pazdur, 1992). Dating of carbonate sediments associated with $d^{13}C$ and $d^{18}O$ determinations is useful for reconstruction of palaeotemperatures (Pazdur *et al*., 1988, Pazdur *et al.*, 2002). Statistical analysis of large sets of ^{14}C dates may be a source of information on global or regional environmental changes. In 1980, M. A. Geyh presented an article in which he discussed possibility of reconstruction of Holocene sea level history on the base of statistical evaluation of ^{14}C dates by histograms. Statistical evaluation of sets of ^{14}C dates has also been applied to studies of climate (cf. Geyh, Rohde, 1972; Goździk, Pazdur, 1987).

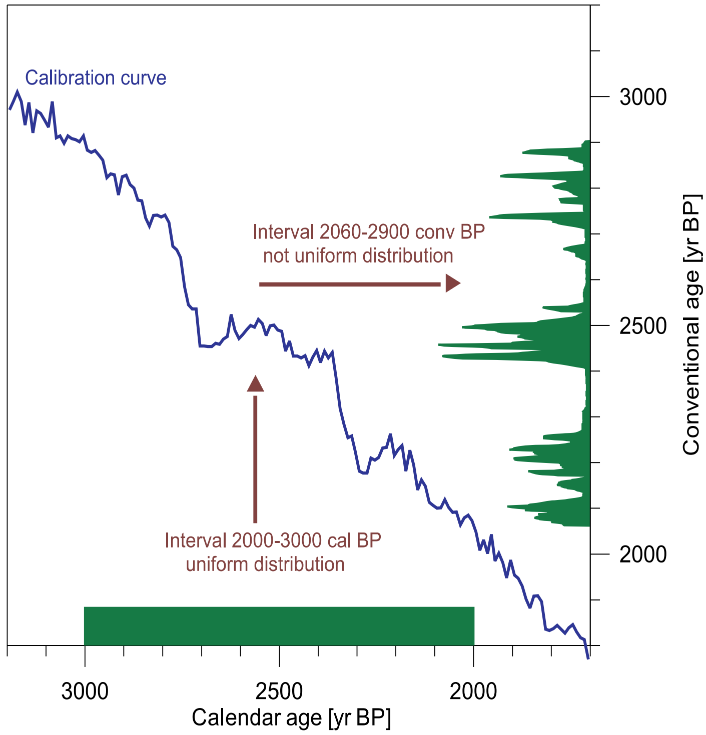
Also applications of statistical analysis of radiocarbon dates in archaeology is permanently improving (cf. Buck *et al.*, 1992; Michczyński *et al.*, in print). Bayesian methods allow to use different types of information for analysis (e.g. stratigraphy, other dating methods), which should make the analysis more precise (Bronk Ramsey, 1995).

PROBLEM OF ABSOLUTE AGE DETERMINATION

It has been known for many years that the ^{14}C concentration varied in the past (de Vries, 1958). Variations in atmospheric ^{14}C content complicate conversion of the conventional radiocarbon ages into calendar ages. In order to overcome these difficulties, the concept of probabilistic calibration of radiocarbon dates and appropriate computer programmes have been introduced (cf. Pazdur, Michczyńska, 1989; Michczyńska *et al.*, 1990; van der Plicht, 1993). It should be emphasised that the differences between radiocarbon and calendar time scale could be a source of misleading impressions on synchronisation of some events, on incorrect estimation of sedimentation rates or on duration of episodes if

[1] GADAM Centre, Institute of Physics, Silesian University of Technology, Krzywoustego 2, 44-100 Gliwice, Poland
[2] Institute of Quaternary Research and Geoecology, Adam Mickiewicz University, Fredry 10, 60-701 Poznań, Poland

Fig. 1. Certain geological event at real (calendar) time scale has uniform distribution between 2 and 3 kyr BP. At the radiocarbon scale we have received adistribution between 2070 and 2905 conv yr BP. It should be emphasised that at the radiocarbon scale the duration of events can from that at the calendar time scale



radiocarbon ages were not calibrated. The correct interpretation of palaeoenvironmental records requires calibrated ages. It is especially significant when comparisons between records from different chronologies (e.g. radiocarbon and varve) are made (Bartlein *et al.*, 1995). Simple simulation shows that an event with uniform probability distribution at some periods of the calendar time scale is not uniformly distributed at the radiocarbon time scale (Fig. 1).

ANALYSIS OF THE FREQUENCY DISTRIBUTION SHAPE OF RADIOCARBON DATES

Since the nineteen seventies, analyses of the frequency distribution of the ^{14}C-dated samples on a time scale have been carried out for several selected geographic regions (e.g. Geyh, Rohde, 1972; Goździk, Pazdur, 1987; Pazdur *et al.*, 1995; Michczyńska *et al.*, 1996). The radiocarbon dating method, primarily used simply to determine age of dated sediment, became an important source of information on the course of some geologic processes in the past. An interpretation of the frequency distributions is based on the two basic assumptions:

— the number of the ^{14}C dated samples is proportional to the amount of organic matter deposited in sediments in particular time periods;

— the amount of organic matter in sediments depends on palaeogeographical conditions.

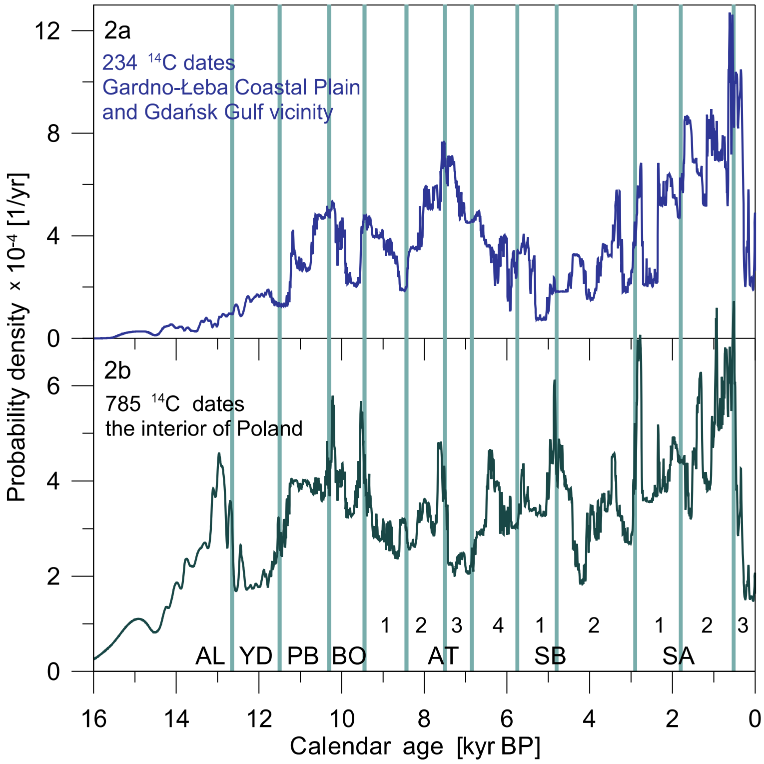
For statistical analysis, dates of peat from Poland were selected. All these dates came from the Gliwice Radiocarbon Laboratory. Peat is a typical organic material, commonly dated with the use of the ^{14}C method. The resulted radiocarbon ages are reliable and do not require any corrections because of „hard water effect" or isotopic fractionation (Pazdur, 1982). These facts decided that this type of deposit was chosen for analysis.

The result of a single radiocarbon dating T ±ΔT is described by Gaussian probability distribution. For a set of N ^{14}C dates, cumulative probability distributions are created by superposition of the individual dates distributions. In our analysis, we assume that fluctuations of such distributions magnitude result from changes of the environmental condition. At the time of favourable environmental condition, accumulation of peat is higher than at the time of unfavourable condition. In the analysis we should take into account several other causes which can hamper the interpretation of the probability distribution. Detailed discussions of this problem are presented elsewhere (Geyh, 1980; Michczyńska, 2003; Michczyńska *et al.*, in print; Michczyńska *et al.*, in preparation).

In this paper, the authors would like to emphasise that critical selection of dates used for such analysis plays a key role. Detailed analysis of probability distributions, constructed for ^{14}C-dated peat samples from the territory of Poland, shows that the preferential sampling influenced significantly the shape of these distributions. The general rule of taking samples from places where sedimentation changes are visible (e.g. from top and bottom of the peat layer) resulted in high narrow peaks of the probability distribution near the boundaries of Holocene subdivisions (cf. Fig. 2). On the one hand, this fact hamper analysis, but on the other, it is useful to establish the boundaries of Holocene subdivision on the calendar scale. An example of probability distribution of over 200 ^{14}C dates from the Gardno–Łeba Coastal Plain and from the vicinity of the Gulf of Gdańsk, is presented in Figure 2a. It is clearly visible that this distribution has quite different shape than the distribution of

Fig. 2. Cumulative probability density functions for the 234 ^{14}C dates from the Gardno–Łeba Coastal Plain and from the vicinity of the Gulf of Gdańsk, and for the 785 ^{14}C dates from the interior of Poland

Vertical lines indicate boundaries of the Late Glacial and Holocene subdivisions (Starkel, 1999; after calculation on the calendar time scale); high narrow peaks near the boundaries are interpreted as results of the preferential sampling



the dates from the interior of Poland (Fig. 2b). This fact probably results from transgression, but precise interpretation is difficult because of the method used for the construction of this distribution: all dates available at the Gliwice Radiocarbon Laboratory Data Bank were used for calculations. Precise selection of dates used for statistical analysis requires co-operation of the scientists working in the radiocarbon laboratory and geologists. Only such an interdisciplinary co-operation ensures valuable results. Co-operation with professor S. Żurek allowed the interpretation of probability density distributions for different regions of the interior of Poland (Michczyńska *et al.*, 2003).

REFERENCES

BARTLEIN P.J., EDWARDS M.E., SHAFER S.L., BARKER E.D., 1995 — Calibration of radiocarbon ages and the interpretation of palaeoenvironmental records, *Quaternary Research*, 44: 417–424.

BRONK RAMSEY C., 1995 — Radiocarbon calibration and analysis of stratigraphy: the OxCala program. *Radiocarbon*, **37**, 2: 425–430.

BUCK C.E., LITTON C.D., SMITH A.F.M., 1992 — Calibration of radiocarbon results pertaining to related archaeological events. *Journal of Archaeological Science*, **19**: 497–512.

GEYH M.A., 1980 — Holocene sea-level history: case study of the statistical evaluation of ^{14}C dates. *Radiocarbon*, **22**, 3: 695–704.

GEYH M. A., RHODE P., 1972 — Weichselian Chronostratigraphy, ^{14}C dating and statistics. Int. Geol. Congr., 24th, Montreal 1972: 27–36.

GOŹDZIK J., PAZDUR M.F., 1987 — Frequency distribution of ^{14}C dates from Poland in the time interval 12–45 kyr BP and its palaeogeographical implications. *Zesz. Nauk. PŚl, Mat.-Fiz.*, **56**, *Geochronometria*, 4: 27–42.

MICHCZYŃSKA D.J., 2003 — Statystyczna analiza danych radiowęglowych w badaniach zmian środowiska naturalnego w przeszłości: 1–110. Arch. Inst. Fizyki PŚl.

MICHCZYŃSKA D.J., MICHCZYŃSKI A., GOSLAR T., PAZDUR A., PAZDUR M.F., 1996 — Statystyczna analiza danych radiowęglowych w badaniach zmian środowiska naturalnego w przeszłości. Wstępne wyniki. *Zesz. Nauk. PŚl, Mat.-Fiz.*, **79**, *Geochronometria*, 3: 193–201.

MICHCZYŃSKA D.J., MICHCZYŃSKI A., PAZDUR A., ŻUREK S., 2003 (in print) — ^{14}C dates of peat for reconstruction of environmental changes in the past. *Geochronometria*, **22**.

MICHCZYŃSKA D.J., PAZDUR A. (in preparation) — Shape analysis of cumulative probability density function of radiocarbon dates set in the study of climate change in Late Glacial and Holocene. *Radiocarbon*.

MICHCZYŃSKA D.J., PAZDUR M.F., WALANUS A., 1990 — Bayesian approach to probabilistic calibration of radiocarbon ages. *In*: Proceedings of the 2nd International Symposium ^{14}C and Archaeology (eds. W.G. Mook, H.T. Waterbolk). Strasburg, P ACT, **29**: 69–79.

MICHCZYŃSKI A., EECKHOUT P., PAZDUR A. (*in print*) — ^{14}C Absolute Chronology of the Pyramid III and the Dynastic Model at Pachacamac, Peru. Radiocarbon.

PAZDUR A., DOBROWOLSKI R., DURAKIEWICZ T., PIOTROWSKA N., MOHANTI M., DAS S., 2002 — d^{13}C and d^{18}O time record and palaeoclimatic implications of the Holocene calcareous tufa from southeastern Poland and eastern India (Orissa). Geochronometria. *Journal on Methods and Applications of Absolute Chronology*, **21**: 97–107.

PAZDUR A., PAZDUR M.F., STARKEL L., SZULC J., 1988 — Stable isotopes of the Holocene calcareous tufa in southern Poland as palaeoclimatic indicators. *Quaternary Research*, **30**: 177–189.

PAZDUR A., PAZDUR M.F., PAWLYTA J., GÓRNY A., OLSZEWSKI M., 1995 — Palaeoclimatic implications of radiocarbon dating of speleothems from Cracow–Wieluń Upland, S Poland. *Radiocarbon*, **37**, 2: 103–110.

PAZDUR M.F., 1982 — Badanie dokładności datowania metodą ^{14}C późnoplejstoceńskich i holoceńskich osadów organogenicznych. *Zesz. Nauk. PŚl, Ser. Mat.-Fiz.*, **41**: 1–81.

PAZDUR M.F., 1992 — Modern aspects of radiocarbon dating method: fundamental concepts and archaeological applications. *Archeologia Moldovei*, **15**: 191–211.

PAZDUR M.F., MICHCZYŃSKA D.J., 1989 — Improvement of the procedure for probabilistic calibration of radiocarbon dates. *In*: Proceedings of the 13th International ^{14}C Conference (eds. A. Long, R.S. Kra, D. Srdoć). *Radiocarbon*, **31**: 824–832.

VAN DER PLICHT J., 1993 — The Groningen radiocarbon calibration program. *In*: Calibration 1993 (eds. M. Stuive, A. Long, R.S. Kra). *Radiocarbon*, **35**, 1: 231–237.

STARKEL L., 1999 — Rola holocenu w ewolucji środowiska i jego stratygrafia. *In*: Geografia Polski. Środowisko Przyrodnicze (ed. L. Starkel): 103–105.

de VRIES H., 1958 — Variation in concentration of radiocarbon with time and location on earth. *Proceedings Koninklijke Nederlandse Academie van Wetenschappen*, **61**, B: 1–9.