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PROBLEMS OF HOLOCENE CLIMATOSTRATIGRAPHY ON THE TERRITORY OF POLAND

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Abstract

The presented climatostratigraphy of the Holocene on the territory of Poland is based on a range of biotic, sedimentological, geomorphological and isotopic records, but also takes into account fluctuations of temperature and hydrological regime. The author upholds the traditional division of the Holocene into three thermic phases and discusses in detail distinct fluctuations in the hydrological regime reflected in the alteration of wetter and drier phases. Although their profiles tend to be blurred, the lower boundaries of the wetter phases, which set off the transformation of geoecosystems (a process reflected in the first clusters of extreme events), may be used to identify regional stratigraphic subdivisions. The superimposed phases of human activity have much smaller spatial extent.

Key words: Holocene, climatostratigraphy, wetter and drier phases

BACKGROUND OF HOLOCENE STRATIGRAPHY

In so far as Quaternary stratigraphy is based on climatostratigraphy, it is in particular valid for the Holocene. For that period we have at our disposal continuous records in terrestrial and marine sediments as well as in ice sheets, some of them providing an annual scale (laminated lacustrine deposits, tree rings *etc*.) and allowing year-by-year estimates. It is the latter data that have been correlated with the instrumental meteorological and hydrological indicators. For the territory of Poland we have continuous records of the last 12,870 years of the annually laminated lacustrine sediments of Lake Goś- ciąż (Ralska-Jasiewiczowa *et al.* 1998) and a 3800-year dendrochronological scale (Krąpiec 1998). The Lake Gościąż profile is used as a standard reference scale for the correlation of results obtained by means of various methods.

In the reconstruction of climatic variations special attention has been paid to biostratigraphic methods. Changes in plant communities under the impact of variations in temperature and precipitation registered in Poland in dozens of dated profiles from lakes and peatbogs have been the subject of a comprehensive study (Ralska-Jasiewiczowa, Latałowa 1996) and their palaeogeographic picture presented in the form of isopollen maps (Ralska-Jasiewiczowa *et al.* 2004). Simultaneously all peatland radiocarbon records reflecting hydrological changes have been analysed using statistical methods (Żurek, Pazdur 1999).

The analysis of Cladocera assemblages has been helpful in estimating fluctuations of lake levels and their trophy (Szeroczyńska 1998), while the malacological method has been used to trace thermic and hydrological changes in carstic, slope and swampy deposits (Alexandrowicz *et al.* 1987).

The parallel use of litostratigraphic methods is particularly important in case of unstable environments. It enables us to recognize temporal changes in vertical sequences of deposits as well as in the transversal sections (of valleys, peatbogs), frequently showing their diachronous character. Among them are the facial changes in lacustrine littoral zones (Niewiarowski 1995, Ralska-Jasiewiczowa *et al.* 1998) and in river valleys. The latter register the channel, overbank and paleochannel facies and parallel fills reflecting phases of various flood frequency (Starkel ed. 1990, Starkel *et al.* 1996). Other aspects of the lithology of deposits are raised in studies on their chemical and isotopic composition, among them on ^{18}O, which point indirectly to variations in temperature and in sediment sources (Różański *et al.* 1992).

An additional role in the construction of stratigraphical division of the Holocene is played by the geomorphological methods, especially in the study of fluvial environment with its terrace levels and generations of palaeochannels formed through cut-offs or avulsions (Starkel 1983, 1990, Kalicki 1991). Palaeochannels deliver parameters for the reconstruction of palaeodischarges (Rotnicki 1991). The lacustrine terraces and levees carry important indications of the fluctuations of lake levels (Niewiarowski ed. 1995, Ralska-Jasiewiczowa, Latałowa 1996).

The main role in dating of climatic changes, apart from annually dated tree rings and annually laminated lake sediments, restricted mainly to selected localities or to shorter events, is played by radioisotopic methods. Some of them cover only the last centuries (^{137}Cs, ^{210}Pb). In the Holocene scale none is as important as the radiocarbon (^{14}C) method, although radiocarbon dates require calibration and accuracy of calibrated ^{14}C ages generally does not exceed 100–200 years. The climatic signal of each date has a restricted local or

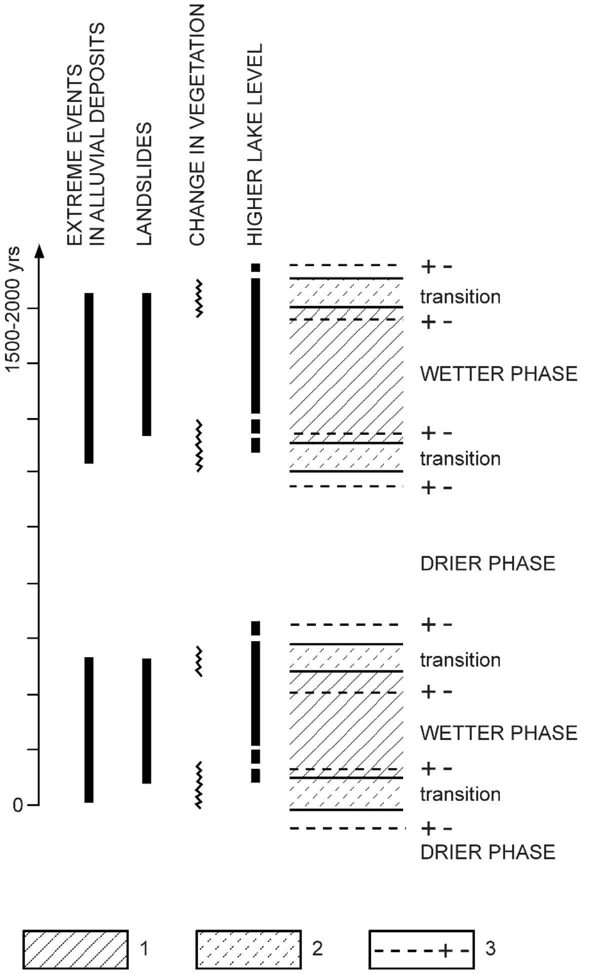

Fig. 1. Imprecise dating and metachronous character of wetter phases during the Holocene (conceptual model). On the left: indicators of heavy rains and wetter periods recorded in various sediments and habitats – floods in alluvial sediments, landslide activity, changes in vegetation, higher lake levels. On the right: imprecise length and flexible time boundaries of wetter phases. *1* – mean duration of wetter phase; *2* – transitional periods; *3* – minimum deviations of radiocarbon dates limits of wetter phase.

regional value and must be correlated with complementary information. The dated sample is usually collected close to the border between two different facies or layers of various granulometric composition, which is assumed to reflect the climatic change (Ralska-Jasiewiczowa, Starkel 1988). Consequently we get data, which is both post-quem or ante-quem in relation to the expected change of climate. While trying to correlate various profiles or various phenomena we should bear in mind that most changes proceeded gradually both locally (like the rising of water level in peat or lacustrine deposits) and on regional scale (like the sucession of species connected with climate warming). Likewise it should be noted that the environmental reaction proceeded at a varying pace, involving some delay in relation to the assumed climatic change (as in the case of glacial advance in relation to heavy precipitations registered in flood sediments).

CHARACTERISTICS OF CLIMATIC CHANGES DURING THE HOLOCENE

The cooling of Younger Dryas was followed by a warming at first rapid ca. 11500 years BP, that gradually, beginning from 5–4 ka BP, reversed towards cooling. This model has been recognised since decades (Lamb 1977). The main climatic changes of the Holocene discernible in the evolution of the vegetation cover, mountain glaciers and depositions of calcareous tufa form the background for the threefold division of the Holocene into a short Eoholocene (which would be much longer if we include about 3 ka of the Late Vistulian, with Bölling and Alleröd), Mesoholocene and Neoholocene or Late Holocene (cf. Firbas 1949, Neustadt 1982). The timing of present interglacial is delayed in relation to the cyclic changes of orbital parameters (Kukla 1969). Holocene temperature fluctuations are relatively gentle with only one rapid shift at the lower boundary, clearly visible in the Gościąż Lake profile.

Distinct hydrological changes which formed the background for the first Scandinavian division of the Holocene with alternate drier phases (Boreal, Subboreal) and wetter ones (Atlantic, Subatlantic) were traced in bog profiles by Blytt and Sernander about a hundred years ago (Sernander 1910). Later, more detailed studies have helped to distinguish a succession of shorter phases also on the territory of Poland. They involve various genetic types of sediments: lacustrine, peatbogs, alluvia, calcareous tufa, colluvia, cave deposits and are especially well readeble in the pollen, malacological and other records. In effect at least 5–8 wetter phases, generally several hundreds years long, separated by relatively drier periods have been recognised in Central Europe (Starkel 2002, 2003a, b, Fig. 2), connected with fluctuations in solar activity (Chambers *et al.* 1999). These variations are reflected in the radiocarbon productivity curve (Stuiver 1995). Most of the phases of reduced solar activity coincide with wetter phases recognised in mountain glacier advances, rises of lake and groundwater levels and in increase of fluvial and landslide activity (Magny 1993, Schrirmer 1995, Margielewski 1998, Starkel 2003a). These phases have been dated in fluvial environment at 8.5–7.8, 6.5–6.0, 5.4–4.9, 4.4–4.1, 3.5–3.0, 2.4–2.0 ^{14}C ka BP, 450–575 AD, 900–1150 AD and 1550–1850 AD (cf. Starkel *et al.* 1996). Some of these phases like 8.5–8.0 ^{14}C ka BP clearly coincided with high volcanic activity, which additionally caused an increase in the frequency of heavy rainfalls (Starkel 1999a). Moreover, in the course of the last 2000–3000 years the processes of environmental changes have been become more complex due to the increased role of human activity, especially since the late Roman period and then during the last millennium causing an acceleration in runoff, sediment load and rise of groundwater level (Starkel 2005).

AGE BOUNDARIES AND INTERNAL COMPLEXITY OF WETTER PHASES

Analysing the age boundaries of single phases on the basis of records of changes in various depositional environments (facies), we may conclude that the recording of beginning and the end of phase in one facies may be neither

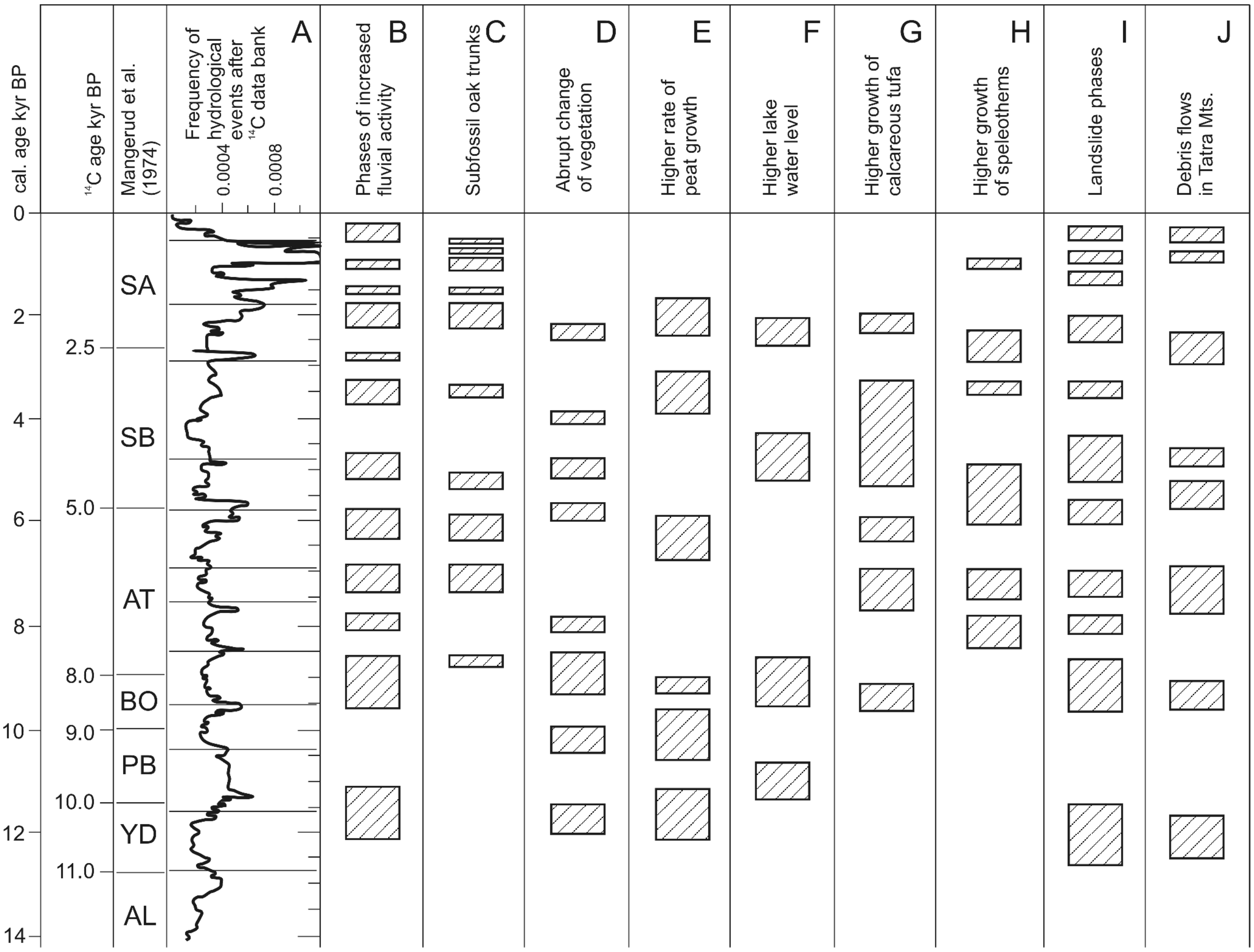

Fig. 2. Phases of wetter climatic expressed in various types of sediments and habitats on the territory of Poland (after various sources): A – Starkel *et al.* 2006; horizontal lines indicate climatostratigraphic units distinguished in S-Polish river valleys by L.Starkel (1990, 1999); B – Starkel 1990, Starkel *et al.* 1996; C – Krąpiec 1998, Starkel *et al.* 1996; D – Ralska-Jasiewiczowa, Starkel 1988; E – Żurek, Pazdur 1999; F – Niewiarowski 1995, Ralska-Jasiewiczowa *et al.* 1998, and others; G – records in Pazdur *et al.* (eds) 1999; H – records in Pazdur *et al.* (eds) 1999; I – Starkel 2003a, based on Margielewski 1998 and others; J – Kotarba, Baumgart-Kotarba 1997.

clear nor synchronous. Even more, a comparison of various environments (facies) shows frequently a distinct metachronity of changes (Starkel 2003a).

The beginning and the end of each wetter phase (generaly, also the cooler one) is first of all burdened with a margin of uncertainity which may exceed 100 years. Then, we have to allow for a period of gradual adaptation of communities or depositional environments to the new conditions characterized by an increase or decline in the rainfall totals and their frequency. Therefore the total fluctuation of the phase boundary may exceeded 200 years (Fig. 1).

At the same time the changes registered in different enivironments show either a rapid response to hydric change or significant delay (Starkel 2003a). The debris flows in the Tatra Mts. were triggered off by high intensity downpours (Kotarba, Baumgart-Kotarba 1997). Continuous rains produced floods directly reflected in the river channel changes and overbank depositions. The onest of a wetter phase resulted also, with some delay, in marked accumulation of cave deposits and in landslide formation. It took much longer for lake levels in the lowlands to rise. Even more delayed in time were the advances of glaciers in the Alps. The impact of the wetter phase on the vegetation cover usually proceeds in two phases, marked by the arrival and retreat of hydrophilous species. With overbank deposits bordered by two members of organic deposition we are in a better position to establish the approximate age of the beginning and end of flood deposition (Starkel *et al.* 2006, Fig. 1).

The construction of regional climatostratigraphic divisions involves the difficult question of where or how to put the boundaries of stratigraphic period. Should they be placed at the beginning and the end of the observed wetter phases or should we accept the diachronous boundaries, in different depositional and biotic environments. This question is complicated by the fact that in many cases we can find only the sediment marking a peak value reflecting the climatic change (like the peak of Alnus in the pollen diagram, the highest lake water level) or we have only a date of a single event like a flood or a debris flow from the beginning or from the late phase of a humid period.

It is here that we touch a substantial question on the internal structure of the wetter phase, the duration of which may

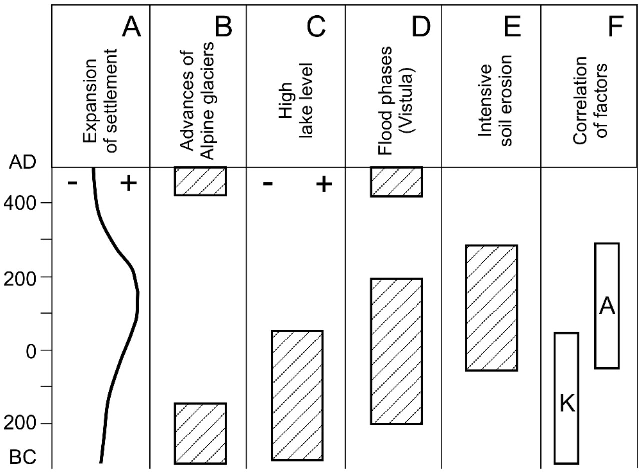

Fig. 3. Influence of climatic and anthropogenic factors on the environmental changes during the Roman period in Southern Poland. The last column shows the relation of climatically (K) and anthropogenically (A) controlled phases of accelerated changes. Following columns are based on records and other data: A – after various archaeological papers, B – Magny 1993 and others; C – Niewiarowski *et al.* 1995, Ralska-Jasiewiczowa *et al.* 1998; D – Starkel *et al.* 1996; E – Starkel 2005; F – Starkel 2003a, 2005.

range several hundreds of years and may be no longer than the margin of error or the length of a transitional period. A detailed analysis of the wetter and cooler periods of the Little Ice Age (Bradley, Jones 1992) shows that a phase of about 300–350 years long comprised several episodes of decadal duration with high frequency of heavy rainfalls and floods which are sepatated by periods of much lower frequency (see: Fig. 2 in the paper by L. Starkel, this volume p. 24). This clustering of extreme events led to serve disturbances and changes in the geoecosystems and finally to the transformation of river channels, floodplains and even plant communities (Starkel 2003a). A detail survey of a small alluvial fan at Podgrodzie in the Wisłoka valley dated between 8400 and 7800 ^{14}C yrs BP has shown that this humid phase of more than regional range also consisted of several clusters of extreme events (Niedziałkowska *et al.* 1977, Starkel *et al.* 1996). With the help of greater number of data from that period from localities in various climatic zones it should be possible to give shape to the concept of the internal structure of wetter phases during the Holocene, characterised by high amplitudes of meteorological parameters and frequent clusters of extreme events (Starkel 1999, see p. 24 this volume).

DISCUSSION

In the 1970-90s, I repeatedly attempted to present a climatostratigraphic scheme for territory of Poland in comparison to other stratigraphic divisions of the European Holocene (Starkel 1977, 1990).

It was based to large extent on the analysis of fluvial sediments and forms in the Upper Vistula basin, where several wetter phases with high frequency of extreme events have been recognized (Fig. 2). The question is if the expresion of that rhytmicity of hydrological fluctuations without sharp boundaries can be a basis for a stratigraphic division of the Holocene in Poland. It should be also mentioned that the territory of Poland has not had an uniform climate, which is indicated not only in the present-day diversity of ecosystems but also by the difficulties encountered in correlation of dendrochronological standards in longitudinal transect across Poland (Krąpiec 1998). At the same time the coincidence of the three main Holocene phases with high lake level (*ca* 8.5–8.0, about 4.5 and 2.5–2.0 ^{14}C ka BP), increased fluvial activity, landsliding *etc*. on the territory of whole Poland indicate that at least these three phases were synchronous (Starkel *et al.* 1996, Starkel 2003b). Therefore I would be ready to uphold my previous principles of Holocene stratigraphy after a minor modification within the threefold division. These lower order boundaries should be placed at the beginning of the wetter phases, because these phases seem to be the main drivers of characteristic changes that followed suit in the geoecosystems (Fig. 2). These beginnings are marked off precisely by the first clusters of extreme events and not by culminations of high lake levels or changes in forest communities (which followed). In agreement with the analysis of biotic and abiotic indicators of changes (cf. Ralska-Jasiewiczowa, Starkel 1988) these relatively shorter humid phases were periods of destruction of inherited plant communities and geomorphic systems. The stabilization of the new systems followed at the close of wetter phases or even later.

Another intriguing question concerns the incorporation of anthropogenic activity phases in the regional subdivision of the Holocene. This question has been discussed by several authors, whose views diverge a great deal (Berglund 2003, Frenzel 2000, Starkel 1993). Taking Southern Poland as a case in point I have tried to demonstrate that the human factor may be superimposed on climatic fluctuations in a number of ways (Starkel 2005). For instance the phase with high frequency of extreme rainfalls during the Dark Ages (5–6th century AD) was expressed in frequent floods with channel avulsion and reforestation but not in overbank deposition (Starkel *et al.* 2005). By contrast, the intensive soil erosion especially in the loess plateaus of Southern Poland during the late-Roman period (1st–3rd century AD) was mainly of anthropogenic origin (Fig. 3). The superposition of intensified human activity on the wetter phases is documented during the Funnel Beaker culture (the transition between 5–4th millennia BC), the period of the Lusatian culture (10–6th century BC) in the 11th century AD and during the Little Ice Age. Human activity, expressed in the acceleration of water and matter circulation, usually had a local or at most regional character. Therefore it would be difficult to include it as one of elements making for the stratigraphic division of the Holocene across the territory of the whole country.

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