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Change in the Frequency of Extreme Events as the Indicator of Climatic Change in the Holocene

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ABSTRACT. The transformation of natural systems in the Holocene by climatic factors is realised by the change in the type of extreme events or by change in their frequency or by both. These changes are exemplified by the transition from the Younger Dryas to the Preboreal and by wetter phases of higher flood frequency and reactivation of slope processes in central Europe.

KEY WORDS: climatic change, phases of high frequency of extreme events, fluvial systems.

The transformation of fluvial systems, both valley floors and slope sectors is realised during extreme events, when the equilibrium is disturbed and tresholds iniciating various processes are passed. Among those events are heavy downpours, continuous rains, rainy seasons, rapid snowmelts combined with heavy rains etc. (Starkel, 1996). Heavy downpours over restricted areas cause extensive slope wash, gullying, earth and debris flows and local floods. Continuous rains of regional scale create various mass movements, piping and flooding in larger catchments. Rainy seasons reactivate deep landslides. Rapid snowmelts depending on the freezing of the ground and rainy components may lead to heavy soil erosion (with shallow earthflow) and ice-jam floods.

Every climatic change means either a change in the type of events, change in their frequency or both. Change in type is exemplified by the shift from snow-melt floods with ice-jams to rainy floods. Change in the frequency could run separate or parallel with the change of type in events.

The case of parallel change of the floods type and frequency may be caused by rapid cooling or warming. At the transition from the Younger Dryas to the Preboreal the Gościąż Lake (Ralska-Jasiewiczowa et al., 1998) and several other localities with annually laminated sediments recorded during several decades a rise of the mean annual temperature of the order of 3–5 °C. Instead of frequent snow-melt floods during the Younger Dryas there followed the Preboreal with less frequent rainy floods. The sediment load was reduced drastically due to expansion of forest communities in the Central Europe. Farther to the North-East in the boreal forest zone the snow-melt floods are still dominating, but their frequency and geomorphic role substancially decreased.

Therefore in dozens of middle reaching central European river valleys are observed rapid changes from braided river channels or large meander to small meanders (Fig. 1), indicating the decline of bankfull discharges by 5 times and more (Szumański, 1983; Starkel, 1990; Rotnicki, 1991; Starkel et al., 1996). This coincides with the decline of sediment load and formation of extensive back-swamps instead of coarse-grained bars and overbank deposits.

The other case of main shift only in the frequency of extremes is represented by several wetter phases during the Holocene characterised by much higher flood frequency (Starkel, 1983, 1998). These floods are responsible not only for a higher deposition rate, for intensive lateral erosion and accretion, but also for the straightening and widening of channels with braiding tendency and avulsions (Fig. 2). During the Holocene in the central Europe there were recognised several such phases; 8.5–7.8, 6.6–6.0, 5.5–4.9, 4.5–4.2, 3.5–3.0, 2.8–2.7, 2.2–1.8 ka BP, 10th–11th century and the Little Ice Age (Starkel et al., 1996).

But we observe that the trend towards differed downcutting or aggradation during particular phases. During the older ones prevailed the downcutting tendency, since Roman or mediaeval time it changed to aggradation due to deforestation and extensive agriculture. The turn to more stable river regime with less frequent floods caused again the stabilisation of river channels and developing of free meanders.

In the case of the Atlantic-Subboreal transition towards a slightly cooler/wetter climate in the global scale, this change in the temperate zone of Europe is accompanied by two distinct phases with higher frequency of extreme events ca 5.5–4.9 and 4.5–4.2 ka BP (Kalicki, 1991; Starkel et al., 1996).

The first of such wetter phases during the Holocene is especially well recorded at Podgrodzie site, where in the small alluvial fan ca 6 meters thick deposited between 8.4–7.8 ka BP the proluvial sands and silts are representing at least 100 heavy rains (Starkel, 1984; Czyżowska, 1997). This indicates that during this phase, both heavy downpours and continuous rains were frequent.

The last cooler phase known as the Little Ice Age is well expressed in deposits and forms due to the higher rate of processes connected with an accelerated runoff and sediment load after extensive deforestation.

The parallel study of fluvial and slope forms and deposits extends our knowledge about the role of change in the frequency as well as in the type of extreme events. Such changes over Carpathian slopes were observed during all phases of increased fluvial activity starting from the phase 8.5–7.8 ka BP up to the Little Ice Age. In the montane belt of the Tatra Mts. above the upper tree line the frequent debris flows are connected with high intensity downpours (Kotarba and Baumgart-Kotarba, 1997). On the contrary the extensive landslides over the flysch slopes were created during the continuous rains and rainy seasons (Starkel, 1985, 1997; Alexandrowicz, 1996; Margielewski, 1997).

During these active phases with very unstable weather and frequent extremes it follows a clustering of various thresholds leading not only to transformation of river channels and slopes favourable to landsliding but also to the lowering of vertical vegetation belts, to advances of Alpine glaciers and to rises of lake water levels (cf. Starkel, 1985; Magny, 1993). The opposite trend is observed after the end of each wetter phase.

About the causes of these phases it prevails the opinion, these reflect either the periods of declined solar activity (Stuiver and Braziunas, 1993; Magny, 1993) or increased frequency of volcanic eruptions (Nesje and Johannessen, 1991) or both (Starkel, 1998). The superposition of decline in solar radiation and spreading of volcanic dust is especially well pronounced 8.5–8.0 ka BP (Bryson and Bryson, 1998; Starkel, 2000). In every case the climatically driven environmental changes registered in sediments and forms are realised through the fluctuations in type and frequency of extreme events.

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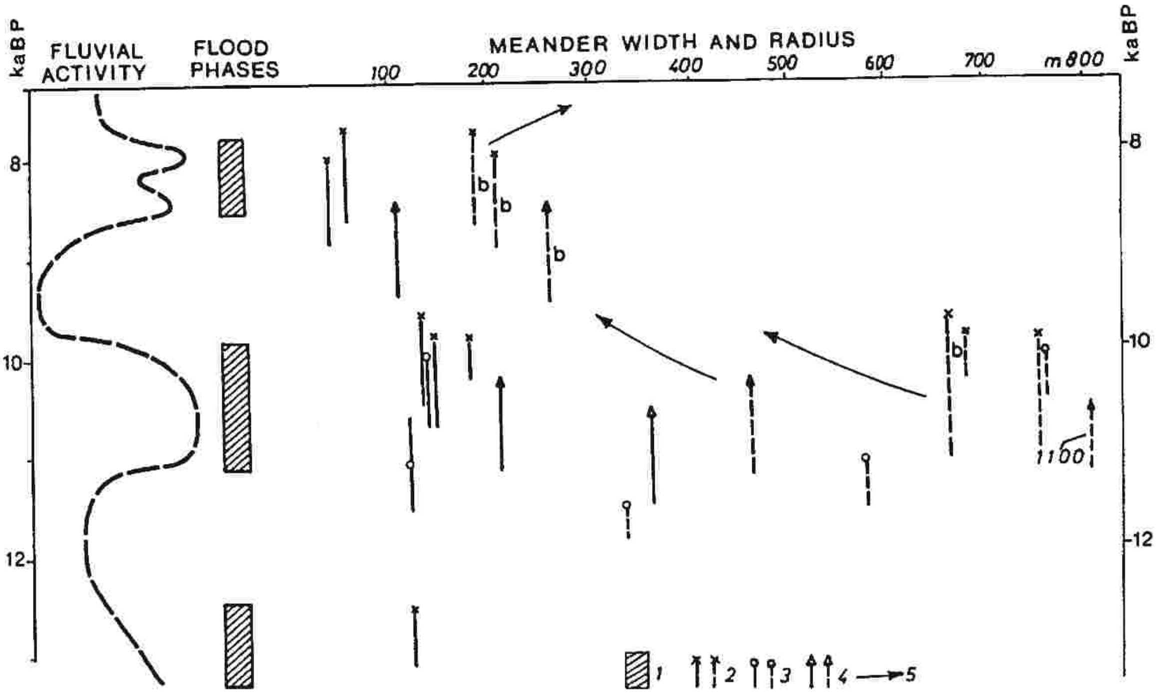

Fig.1. Parameters of paleochannels from the Younger Dryas and early Holocene (after Starkel et al., 1996).
1. main flood phases, 2. (a) width and radius of paleomeanders in the upper Vistula valley, (b) downstream of Cracow, 3. width and radius in the Wisłoka valley, 4. width and radius in the San valley, 5. direction of changes (increase or decrease).

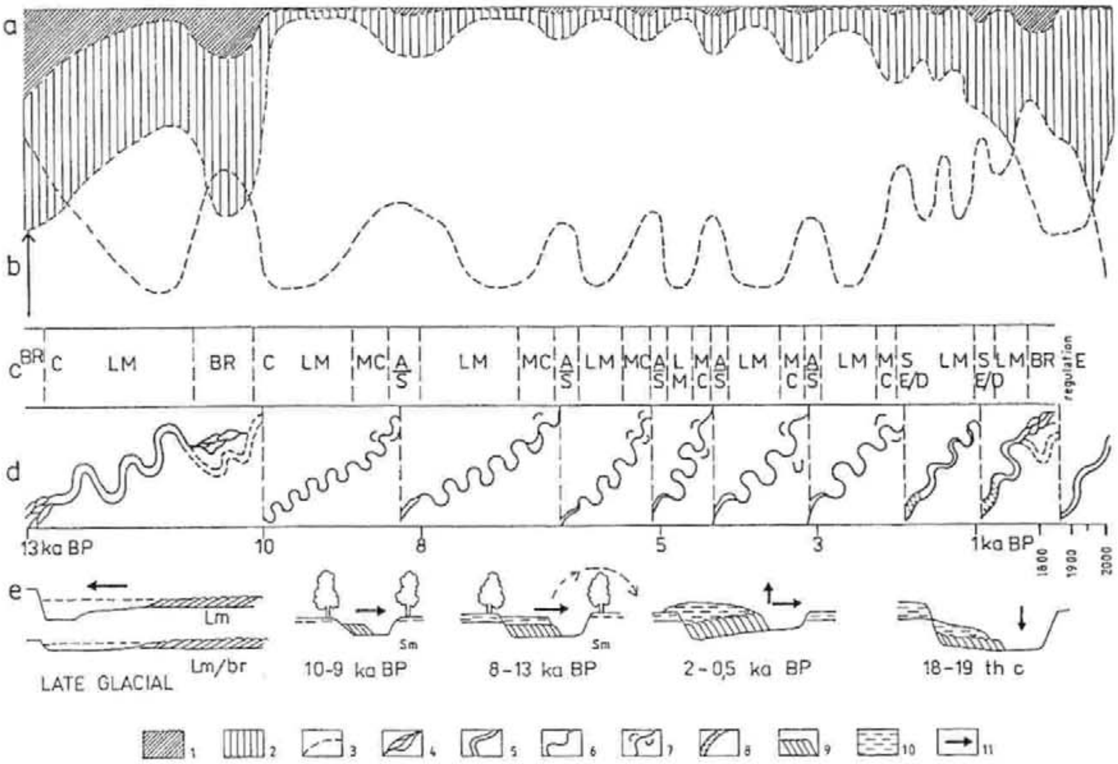

Fig. 2. Model of rhythmic changes and thresholds in the evolution of river and flood plains during last 13,000 years (after Starkel et al., 1996).
(a) relative fluctuations of transport and delivery of bedload and suspended load, (b) fluctuations in flood frequency (Kalicki, 1991; Starkel, 1994), (c) main directions of changes: BR - braided channels, C - concentration of channels, LM - lateral migration, MC - meander cutt-off, A - avulsions, S - straightening, E - downcutting, D - aggradation; (d) rhytmic changes of channel parameters, various cycles are separated by threshold changes in the fluvial system, (e) schematic channel cross-sections and directions of their transformation during various phases of the Late Vistulian and Holocene. 1 - bedload, 2 - suspended load, 3 - curve of flood frequency, 4 - braided channel, 5 - large paleomeanders, 6 - small paleomeanders, 7 - cut-off meanders, 8 - incision of the straightened channel, 9 - channel bars, 10 - overback deposits, 11 - directions of channel changes.

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Late Quaternary Sedimentation History of the Lena Delta

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ABSTRACT. The Lena River draining to the Siberian Arctic is considered to be the main sediment source for the Laptev Sea. Nevertheless, the delta of the Lena River occupying an area of 28,000 km^2 *is a poorly studied and very complicated region of Land-Ocean-Interactions in the Arctic. To understand the sedimentation and environmental history of the Lena delta different geological and geophysical approaches were applied. To identify sedimentary and permafrost structures within the Lena delta sampling of sedimentary sequences by shallow coring and through natural exposures, ground penetrating radar and shallow seismic studies have been carried out. Age determinations are based on radiocarbon and OSL dating.*

Mineralogy and geochemistry of the sediments show that the Late Quaternary conditions of accumulation and deposition in the Delta area are of purely fluvial nature and any marine ingression can be excluded. A radio-echo sound (RES) system proved to be a valuable technique for mapping subsurface structures on land and lake sediments. The 100 MHz radar signal penetrated the permafrost down to 80 m at maximum showing periglacial features like ice wedges and ice layers. Seismic surveys complemented lake sediment profiling to characterize the geometry of basin fills, changes in lake sedimentation, and to identify the permafrost table below talik zones. Sediment drilling is used to verify the geophysical profiling.

KEY WORDS: Lena Delta, permafrost, Late Quaternary environment, fluvial sediments, lake sediments, Arctic Siberia.

Introduction

Studies of Arctic delta processes, delta morphology and facies development are relatively limited compared to the extensive literature on low-latitude deltas. Whereas the development on all deltas is governed by the interaction of sediment supply, the stability of the receiving basin and wave and tide processes, an additional primary factor in Arctic delta settings like the Lena Delta is the influence of climate, i.e. ice. The effects of ice are reflected in the sedimentary facies of the delta on sediment processes at the river mouth. Patterned ground formed by thermal contraction and present in sediments original as ice wedges or preserved as small, v-shaped sand wedges provides the most direct sedimentological indicator of the arctic climate and is widely spread in the Lena Delta plain. However, winter ice and permafrost also govern the stratigraphic development of interchannel and channel-mouth deposits. Ice cover confines flow at primary channel mouths, promoting the bypassing of sediments across the delta front during peak discharge in spring. Permafrost minimizes consolidation subsidence and accommodation near the shore, further enhancing sediment bypass. Storms limit the seaward extent of bar development and promote a distinctive pattern of upstream and lateral island growth. And despite a low tidal range and relatively low wave conditions, the Lena Delta is not prograding seaward but rather is undergoing transgressiv shoreface erosion (Rachold et al., in press). During the last two decades scientists studied geomorphology, cryolithology, hydrology, paleogeography, tectonics, permafrost, the greenhouse gas flux, Quaternary geology etc. in the area (Korotaev, 1986; Galabala, 1987; Kunitsky, 1989; Grigoriev, 1993; Fukuda, 1993; Alabyan, 1995; Rachold, 1996; Are, 1999). But although the Lena Delta is the main connection between interfering continental and marine processes within the Laptev Sea the sedimentation history of the Lena Delta, its importance as a fossil accumulation area, age relations between the main fluvial terraces, as well as the processes that control the lateral extension, are poorly understood.

Methods and material studied

According to Grigoriev (1993) the Lena Delta area can be subdivided into three major geomorphological terraces. While the main part of the eastern Lena Delta is assumed to be an actual "active" delta (first terrace) the western part consists of mainly sandy deposits (Arga Island, second terrace) and Ice Complexes (ice-rich silty peat accumulations, third terrace) of different age and origin (Rachold et al., 1999). Sedimentation and permafrost conditions in the western and in the eastern part reflect different phases of fluvial deposition depending on climatic, tectonic and/or glacial controls during the Holocene and the Late Pleistocene. Geological sampling and geophysical surveys have been conducted both on land and on lakes at representative sedimentation sites in the delta area (Fig. 1). To identify sedimentary and permafrost structures within the Lena delta sampling on land was done by permafrost drilling to recover