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Fan sediments as indicator of gully erosion stages on the example of the Suwałki Lakeland (NE Poland)

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Abstract: Study of sediments at gullies mouths conducted in the Suwałki Lakeland (NE Poland) showed that fan sediments are significantly diversified. The changes of sediment type could be linked to forest clearance and farmland expansion. Dating and lithological properties of fan sediments allowed to determine the stages of gully erosion. The research also included studies of sediments accumulated within last 200 years in 6 small gully catchments of different degree of cultivation. Supply of the sediments derived from soil erosion to the gully fans was very limited in catchments where only 15% of the land was cultivated. This process was intensively active in catchments where cultivated land occupied 77% of the area.

Keywords: gully erosion, settlement, fan deposits, sediment properties, land use

Introduction

It is commonly believed that the development of gullies is linked to forest clearance and introduction of land cultivation (Maruszczak 1989; Bork 1989; Buraczyński 1989/1990; Bork et al. 1998; Sinkiewicz 1998; Stankoviansky 2003). Gully erosion stages are correlated with consecutive stages of human settlement. Whilst only singular gullies were developed during the Neolithic Age (Śnieszko 1995), much more during the Bronze Age, but majority of contemporary gullies in Poland and neighbouring countries started to develop within the last millennium (Bork et al. 1998; Dotterweich 2009). Climatic conditions are believed to play only secondary role (Lang 2003, Klimek 2002, 2003, Zolitschka at al. 2003; Dotterweich 2005; Starkel 2005).

The research on sediments originated from the gully erosion was conducted in NE Poland in the Suwałki Lakeland. The aim of the research was to determine lithological features of the sediments in relation to stages of the gully development. Selected features of the sediments building fans at mouths of the gullies were previously studied by E. Smolska (2005, 2007). This paper is focused on sedimentological features which allow to determine the source of the sediments.

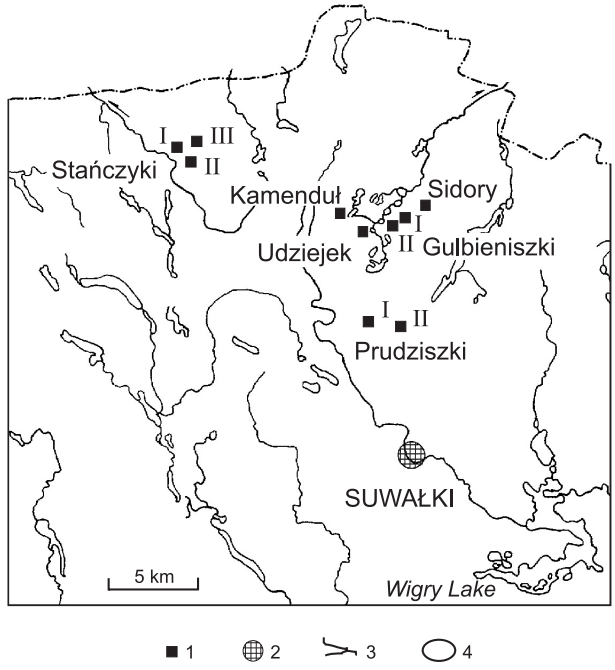

Fig. 1. Location of study fans at the mouths of the gullies: 1 – fans at the mouths of gullies, 2 – town, 3 – rivers, 4 – lakes

Table 1. Comparison of land use and sediment type in fans at mouths of the gullies for chosen small gullies catchments

Gully catchment	Stańczyki III	Sidory	Udziejek	Gulbieniszki	Stańczyki II	Kamenduł
Area [km^2]	0.047	0.215	0.156	0.113	0.032	0.185
Forest [%]	17.5	12.8	7	12	82	100
Grassland [%]	5.2	44.2	55	57	11	0
Arable land [%]	77.3	43	38	31	15	0
Type of sediment: proluvial	XX	X	X	X	X	X
coluvial		X	X	X	x	

X – occurrence of sediment, x – admixture of sediment

Methods

Nine fans were selected for the research (Fig. 1), including two which were subjects of the master theses (Wasilewska 2001). The structure of the fans was checked by hand auger drillings and pit exposures at distal, middle and proximal parts of each fan. Lithofacies were determined in the filed and samples were taken for the laboratory analyses. The age of the sediments was determined by the radiocarbon dating of (1) peat found directly under the fan sediments, and (2) organic matter from humus horizons found within the fans.

The granulometry composition was established with a use of sieves and areometer, and content of organic matter was determined by loss on ignition. Mean size diameter, standard deviation, skewness, fifth percentile were calculated to characterize of granulometry of sediment.

Forest cover density was analyses on following maps as: Topographic Map of the Polish Kingdom (edition 1830–40) 1:126,000, Map of Western Russia 1:100,000 from 19/20th c., Map of Military Geographic Institute 1:25,000 from 20th c. Historical data on settlement in the Neolithic times and folwarks, were also analysed.

Age of the upper youngest units were determined for six fans. Archaeological artefacts that were found in two pits in fans, testified of young age of sediments. These fans were selected in order to compare sediment features with land use in catchments of the gullies. Selected catchments are characterized by different forest area (Table 1). The structure and granulometry of the youngest sediment unit of the gully fans was checked in pits.

Results and discussion

Stages of gully erosion recorded in fan sediments

The thickness of the fans, age of the sediments, and diversification of the sediments allow to determine stages of the gully erosion (Smolska 2007) (Fig. 2A). The oldest age of fan sediments indicate that the first stage of gully development started from 3520±70BP to 2240±100BP. Floors of steep and small dry valleys became dissected and later the incisions widened which resulted in deposition of the lower (older) sediment unit of the fans at mouths of larger gullies. This erosion, occurring along dry valley floors, was initiated probably by climatic factors before forest clearance and can be linked to intensification of fluvial processes during this time (Starkel 2001, Kalicki 2006). According to archaeological data, agricultural history in NE Poland begun with the arrival of the Balts (800 BC). Deforestation process was relatively slow (Brzozowski et al. 1993). Available limited palynological data provide further evidense for gradual and slow introduction of land cultivation (Stasiak 1971, Kupryjanowicz 2004, Szwarczewski & Kupryjanowicz 2006). This stage of erosion and sedimentation lasted until the 3rd century AD, but sometimes much longer, up to 14th–15th century AD in the northern part of the Suwałki Lakeland (Smolska 2007). A sediment unit connected with the first stages of gully erosion is diversified in terms of granulometry (the mean grain size being from 0.5 to over 3 phi), moderately or weakly sorted, and has negative skewness. Organic matter content is very limited (< 0.25%) in this unit (Fig. 2B). Such features make the sediments alike alluvium. In this case, the proper name of sediments derived from the gully erosion should be proluvium.

The second stage of gully development (from 3rd do 7th century AD) was characterized by a significantly slower rate of sedimentation on the fans (Fig. 2A), but there was a simultaneous aggradation in the floors of gullies. Gradual change of sedimentation during this stage is recorded in sediments (Fig. 2A). Most of all, there was an increase in fine, massive material being rich in organic matter (mainly humus and dispersed charcoal pieces). Such features can be linked to forest clearance which gradually became widespread. This increased effectiveness of wash bringing eroded soil to the gully floors.

The third stage of gully development could be connected with settlement of the Jadvings, in the 7th century AD according to the archaeological dating

(Brzozowski et al. 1993). The Jadving culture dominated on the study area up to 13th century, when wars with the Teutonic Order broke out. Sediments of this unit are characterized by (1) significant share of the fine fractions (30–40%, sometimes even 50%), (2) high humus content (3–6% OM), (3) weak or very weak sorting and positive skeewness. Such features are typical for colluvium derived from soil erosion (deluvium). This change in the sedimentological features was accompanied by an increasing rate of sedimentation in the fans, estimated on 2 mm per year on average (Fig. 2A). This was a result of a frequent delivery of fine eroded material from the humic soil horizon which was not protected by forest any more. During this stage, new small gullies started to develop. Such gullies have fans built with deluvium type of the sediments and that allows to suggest that they originated on cultivated slopes (Smolska 2007).

The forth and the last stage (from 14th to 15th century AD) is characterized by intensive dissection of

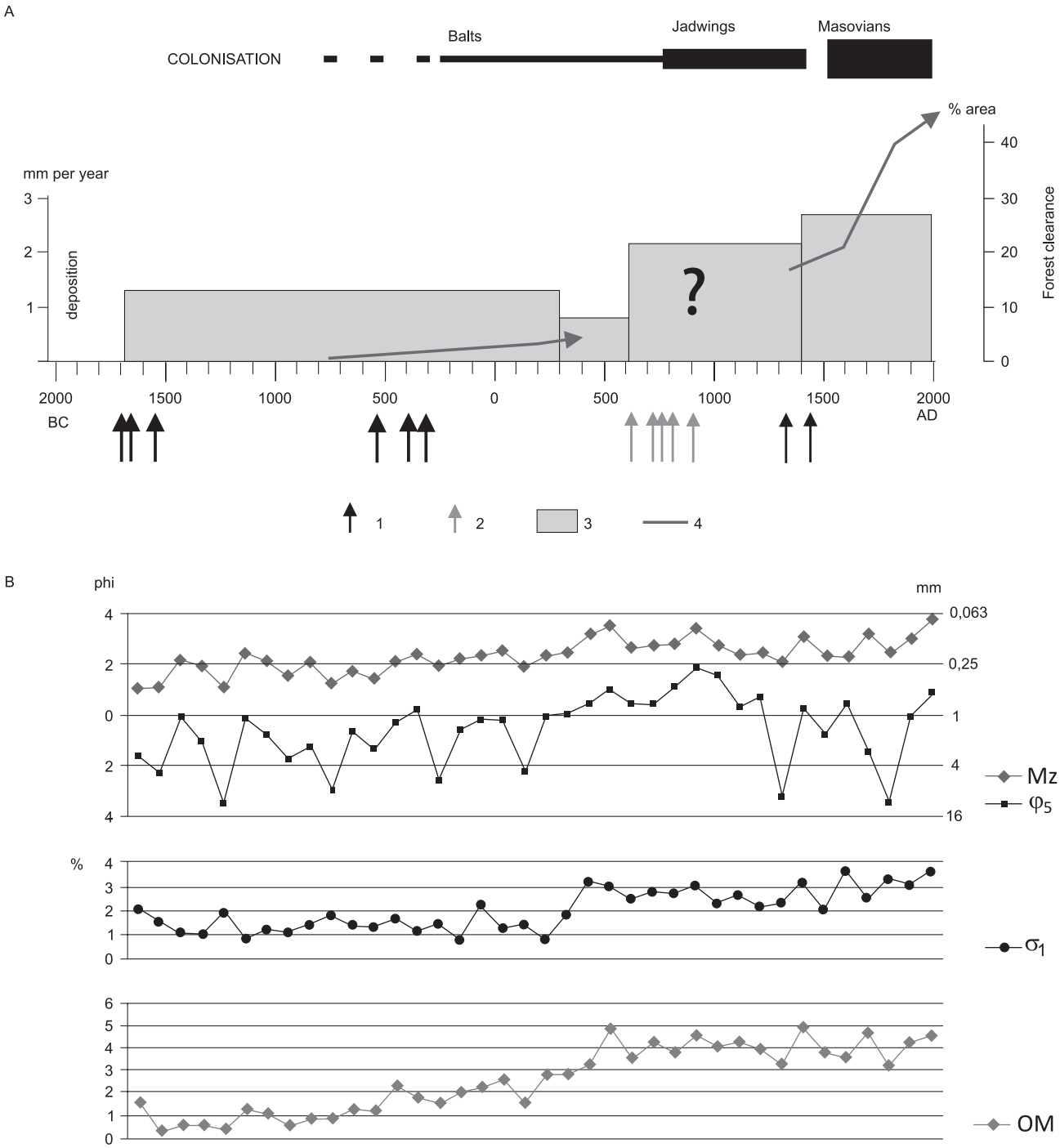

Fig. 2. Stages of gully development on the background of colonization of study area (Smolska 2007) (A) and chosen sediment properties of fans on Udziejek example (B): 1 – initiation of gullies development, 2– further incision of gullies, 3 – intensity of fan deposition, 4 – forest clearence rate after Stasiak (1971), Mz – mean grain size, φ_5 – fifth percentile of the size distribution, σ_1 – sorting index (standard deviation), OM – % of organic matter

large gully infillings. The rate of sedimentation on the fans is estimated to be 2.4 mm per year on average (Fig. 2A). Such high rate of sedimentation is reflected in granulometrical composition of the youngest unit of the fans. They are characterized by a significant diversification of grain sizes (from gravel to loams). The granulometry composition suggests intensive surface wash events and large delivery of fine deluvial material, rich in humus, which originated from deforested catchment areas mainly from soil erosion. Layers of coarser sediments were delivered from the gully erosion. Deposition of two types of sediments: from soil erosion and from gully erosion (deluvial-proluvial sediments), interpreted as a result of human action and climatic changes, resulted in a high rate of deposition on fans. New in-migration movement from Lithuania and Masovia, leading to the final establishment of settlement network, was accompanied by increased rainfall and snowmelt associated with the Little Ice Age.

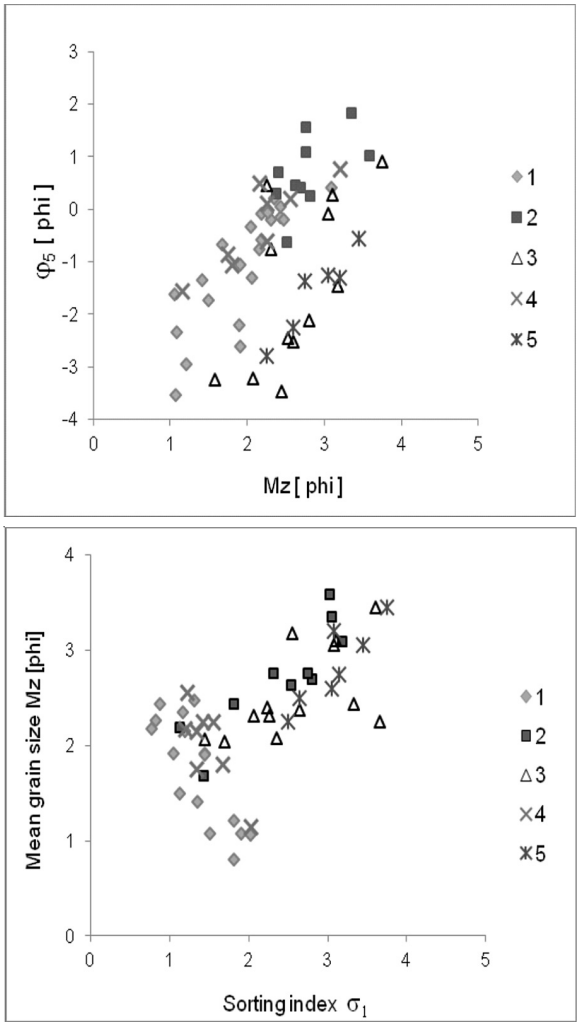

Fig. 3. Relationships between mean grain size Mz and the fifth percentile of size distribution (A) and sorting index σ_1 (B) for fan deposits on example of Udziejek fan: 1 – proluvial sediment (older unit: 3,500–1,700 BP), 2 – deluvial sediment (middle unit: 1,700–1,000 BP), 3 – deluvial sediments (younger unit), 4 – the youngest sediment (last 200 years) from forested gully catchment (Kamenduł), 5 – the youngest (last 150 years) sediment from deforested catchment (Stańczyki III)

Fan sediment properties as indicators of land deforestation

The fans developed at the mouths of gullies are built with two different units of sediments: the older which resembles alluvium (proluvium) and the younger constituted by typical colluvium (deluvium). Only some fans, e.g. near Udziejek or Prudziszki, have an additional sediment unit deposited between the two mentioned. This unit represents the second stage of gully erosion in the study area and shows a gradual change in the character of sedimentation, which resulted from forest clearance in the catchment areas and introduction of agriculture. The third stage of gully erosion is recorded by deposition of almost exclusively deluvial sediments. Majority of the studied fans show a lack the transitional sediment unit which suggest a rapid change of sedimentation. An important question remains: how widespread should be the forest clearance in the gully catchment to trigger a change in sedimentation character on the fans?

Different granulometric indices for the sediment units were analysed. In sedimentological research particular attention is paid to relation between selected parameters, e.g. the mean grain diameter (Mz) and standard deviation (sorting), or the mean grain diameter and the fifth percentile (φ_5). Such relations allow to deduce about the processes of transportation and deposition of sediments (Passega 1964, Mycielska-Dowgiałło 1995).

Usefulness of selected granulometric indices in determining processes of sediment transportation and deposition was emphasized in previous research (Twardy 2002, Smolska 2007). The mean grain diameter together with standard deviation for the researched fan sediments is shown on Figure 3A, and comparison of the mean grain size diameter and the fifth percentile is shown on Figure 3B. Two types deluvial and proluvial sediments are reflected by different relationships between those parameters.

In the next stage of research, six gully catchments were selected. The catchments have been deforested from the 19th century. The Topographic Map of the Polish Kingdom (edition 1839) and Reymann's Spatial Karte (edition 1832–1870) shows that all the area under study, except catchments of Kamenduł and Stańczyki II, was already deforested by the time of the maps elaboration. Selected parameters of the catchments are shown on Table 1. The structure and granulometry of the youngest sediment unit of gully fans was presented on Figure 3. The relationships between sedimentological parameters (Mz-δ_1 and Mz-φ_5) determined for older units are found in sedi-

ments of two youngest units, but only from Stańczyki I and Kamenduł. In the case of Stańczyki I, the youngest unit of fan consists of deluvial sediment deposited at the mouth of the gully of a deforested catchment. The second unit is proluvium derived from completely forested catchment at the Kamenduł site. Both sediment types were found in fans developed in the rest of catchments with diversified forest cover density (Table 1). Analysis of contemporary sediments shows that introduction of arable land on up to 15% of the catchment area does not cause significant change in sedimentation type at the gully mouths. Such situation results in predominant deposition of proluvium. On the other hand, introduction of arable land on 77% of the catchment area (Stańczyki I) bring complete change in the sedimentation on the fans.

Conclusions

Four stages of gully erosion in the Suwałki Lakeland were determined, based on archaeological data, age and lithology of the sediments building the gully fans. The mean grain size diameter, standard deviation (sorting), the fifth percentile and organic matter content allow to infer about transportation processes and source of the fan sediments. The mentioned features allow to distinguish sedimentological units deposited due to soil erosion acting in deforested gully catchments in the post-glacial landscape.

Changes in land use spanning last 200 years were analysed based on historical and cartographical data. Six gully catchments of different density of forest cover were select in order to check the structure and granulometry of the youngest sedimentological unit of the fans. Introduction of arable land on up to 15% of the catchment area very weakly reflects in deposition at the gully mouths. On the other hand, 77% share of arable land results in significant erosion of soil followed by its deposition on the fans. This issue calls for further research and verification in different landscapes.

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