GEOCHRONOMETRIA 38(4) 2011: 325-333
DOI 10.2478/s13386-011-0025-6

Available online at
www.springerlink.com

RELATION BETWEEN RADIOCARBON, ARCHAEOLOGICAL DATING AND SEDIMENT PROPERTIES ON THE EXAMPLE OF COLLUVIAL DEPOSITS (NE POLAND)

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Received 15 June 2010 Accepted 15 March 2011

Abstract: This study focuses on the analysis of the structural and textural features of the colluvial (deluvial) deposits in the Suwałki Lake District (NE Poland) and their absolute age. The colluvium has a thickness of up to 150 cm. The dates of the peat under colluvium or lowermost fossil humus-rich horizons point to the ages from 5405±80 BP to 480 BP. Deposition of material at the footslope is a result of a denudation triggered by human action (surface water erosion and tillage erosion) and usually corresponds with the settlement stages. The ^{14}C dating of deposited sediment sometimes indicated to older dates of colluvium then the archaeological evidence available for examined sites. Locally, the overlying fossil humic horizon was older then the lowermost one. The textural features of the colluvial deposits such as: the content of fine fraction, weak sorting and relationship between the mean grain-size (Mz) and the sorting index (σ_1) were used to recognize sediment redeposited from the upper part of the slope. Basing on the mineral composition and electrical conductivity of fossil humus horizon it is possible to say whether the soil was degraded or aggraded. These features of the humus-rich horizons occurring between colluvial sediments can be used to explain discrepancy between the radiocarbon dating and archaeological evidence.

Keywords: colluvium, fossil soil, sedimentological features, radiocarbon dating, settlement, NE Poland.

1. INTRODUCTION

Finding correlation between stages of slope erosion and archaeological data is very important when analysing colluvial deposits originated from soil erosion (deluvium). Human settlement of the research area, followed by forest clearance and introduction of agriculture, triggered water soil erosion on slope and redeposition at footslopes and in dry valleys (Starkel, 1988, 2005; Bork, 1989; Klimek, 2003; Zolitschka *et al.*, 2003; Wilkinson, 2003). Numerous studies show a good correlation between radiocarbon age of colluvium and settlement stages (Sinkiewicz, 1993, 1998; Twardy, 2002; Lang, 2003). However, in certain morphological situations there are discordances between absolute age of the slope deposits and age of the culture horizon (Śnieszko 1991, 1995; Smolska 2003; Bluszcz *et al.*, 2007).

Difficulties in proper dating of the slope deposits have been reported (Pazdur MF, 1995; Bluszcz *et al.*, 2007; Pazdur A, 2007). The studies emphasized the role of numerous parts of slopes as source areas, the role of different fragments of small catchments and the fact that the slope deposits undergo multi-stage redeposition at footslopes and on floors of depressions or dry valleys. Local-

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ISSN 1897-1695 (online), 1733-8387 (print)

ly, layers of the slope deposits can be arrange in an inverted sequence, and sometimes impossible to date due to admixtures of humic matter of different age. Sinkiewicz (1998) and Lang and Hönscheidt (1999) elaborated a scheme of redeposition of the slope deposits.

The previous research on slope deposits conducted in the Suwałki Lakeland in NE Poland focused on the thickness, lithology and age of the deposits (Smolska, 2005, 2007). Selected sedimentological features were analysed and correlated with settlement stages (Smolska, 2003, 2005; Smolska and Szwarczewski, 2009). The aim of this article is to analyse relations between features of the colluvium, settlement stages and radiocarbon age of the deposits. Particular attention was paid to indicative features which allow inferring about the course and dynamics of geomorphological processes during deposition of the colluvial units (sediment layers). Particular attention was paid to sedimentological features allowing to infer about the course and dynamics of agradation-degradation processes. This was especially important when radiocarbon dating disaccorded with archaeological data.

2. METHODS

Thickness and lithology of colluvial deposits were determined in pits and shallow drillings at the footslopes. Sedimentary units were determined in the field and for each unit granulometric analysis was performed with use of sieves and a settling tube. The organic matter content was determined based on loss on ignition. Electrical conductivity was checked in selected vertical profiles, and content of heavy minerals was checked in selected samples.

Granulometric indices: the mean grain size diameter (Mz), standard deviation (σ_1) and skewness (Sk_1) were calculated based on Folk and Ward (1957) formulae, and the weathering index (W) based on Racinowski and Rzechowski (1969).

The age of the slope deposits was determined based on radiocarbon dating of peat found under the colluvium and humus-rich layers or buried soil horizons occurring within the colluvium (**Table 1**). Radiocarbon age was calibrated with CALIB REV. 4.2.2 (Stuiver and Reimer, 1993) and calibration curve IntCal04 (Reimer *et al.*, 2004).

Archaeological and historical data pertaining to human settlement were also analysed.

3. STUDY AREA AND SETTLMENT HISTORY

The Suwałki Lakeland is characterized by a postglacial relief, typical for the last-glaciation (Weischelian) areas. Undulating and hummocky ground moraine surface prevail in the area. There are numerous hills of terminal moraine and dead ice moraines. Wide depression developed in the area due to glacial erosion and dead ice melt-out. Floors of the depressions are marked with aerial deglaciation landforms. Subglacial tunnel valleys are also frequent.

Table 1. *Age and thickness of study colluvial deposits at footslopes.*

No	Location of slope	Relief	Thickness of human induced colluvium	Type of dated material	Age of human induced colluvium	
					BP	Cal. (range 68%)
1	Łopuchowo 1	kame hill	55 cm	soil	3160±70 Ki-7962	1523-1367 BC
2	Łopuchowo 2	kame hill	80 cm	soil	2740±70 Ki-10281	945-808 BC
3	Prudziszki 1	hill of moraine	70 cm	organic mud	2500±90 Ki-10362	790-510 BC
4	Prudziszki 2	hill of moraine	65 cm	peat	5405±80 Ki-10280	3340-3220 BC
5	Udziejek 1	valley side	95 cm	soil	1650±60 Ki-7963	336-440 AD
6	Udziejek 3	valley side	80 cm	organic mud	1310±60 Ki-10366	661-728 AD
7	Gulbieniszki	hill of moraine	110 cm	soil	1160±100 Ki-7961	776-982 AD
8	Gulbin	slope of depression	80 cm	organic mud	1070±70 Ki-10366	661-728 AD
9	Gulbin	slope of depression	55 cm	peat	380±35 GdA-1722	1450-1516 AD
10	Potasznia	valley side	20 cm	organic mud	1005±70 Ki-10726	977-1098 AD
11	Kameduł	kame terrace	90 cm	peat	860±130 Gd-10869	1150-1264 AD
12	Smolniki	slope of depression	75 cm	soil	460±70 Ki-7964	1420-1560 AD

Denivelations are moderate and reach 15-30 m, and only locally exceed 50 m. Slopes are inclined from 6° to 18° and have convex-concave or straight shapes. Locally, there are dry valleys or gullies developed on the slopes.

The Suwałki Lakeland lies in the temperate continental climatic zone with annual precipitation from 464 mm to 783 mm, and the mean annual air temperature 4.4°-7.8°C.

The region was first settled by farmers, the Balts, about 700 BC (Brzozowski *et al.*, 1993; Bitner-Wróblewska, 1998). Forest clearance proceeded slowly. At the beginning of the mid-Subatlanic period the deforestation with a slush-and-burn method covered up to 5-7% of the region (Stasiak, 1965, 1971), therefore anthropogenic soil erosion could occur only locally. Significant development in agriculture and crafts started at the beginning of the Middle Ages and is associated with the Jatvings. Stabilization of the settlement network occurred during in-migration from Lithuania and Masovia in 15th and 16th centuries.

Colluvial deposits were researched in the central part of the Suwałki Lakeland as well as in its north-western and southern parts (**Fig. 1**).

4. RESULTS AND DISCUSSION

Features of colluvial deposits and their age

Colluvial deposits found at footslopes are usually 0.5 to 1.5 m thick, however, in places maximum thickness reach 1.8 m. Structure of the deposits is shown in **Fig. 2**. Most frequently, they are composed of mixed sands, locally with an admixture of fine gravel or silt and clay. In general, three sedimentary units can be distinguished within the deposits. The lowermost (oldest) unit is 20-50 cm thick with horizontal layering or lamellar structure and flow structures in places. The next unit, 20-50 cm thick, is lamellar or massive with an admixture of organic matter. Usually, a fossil soil horizon can be found at the top of this unit. The uppermost unit, 60-120 cm thick, is a structureless homogenous sediment and includes dispersed humus and fine charcoal pieces. Lack of any sedimentary structures can be attributed to cultivation of the slope. The three units occur at the footslopes together in one sequence only locally. Usually, only two units or one (the uppermost) unit can be found at the footslopes.

Fig. 1. *Location of study sites*

The age of the colluvium triggered by human action usually correlates with archaeological data relatively well (**Fig. 3**). Significant variations in the age of the deposits relates to the settlement stages of the researched area and shows gradual enlargement of the deforested slopes by the Balts and then the Jatvings and during the last phase of the settlement in 15th and 16th century (Smolska, 2007; Smolska and Szwarczewski, 2009). However, in certain cases the radiocarbon age of the deposits does not correlate with archaeological data (**Fig. 3**). Such cases were closely analysed (**Fig. 4**).

Łopuchowo – inverted age of the deposits

Dating of fossil soil horizons can sometimes produce inverted age. Most of the attention was paid to archaeological artefacts of different age found in one sediment layer and to development of soil horizons. Sedimentological features of the deposits were usually disregarded.

The structure of the slope cover in Łopuchowo, 1.5 m thick, is shown in **Fig. 2**. The lower unit of the colluvium is composed of sands with no organic matter. Some flow structures can be observed at the floor and layering at the top of the unit. Thickness of this unit is only 35-40 cm. Gradual increase of the organic matter content (from 0.2% to 1.5%) is observed in the middle unit of the colluvium (**Fig. 4A**). Fossil soil horizon (c. 3% OM) occurs at the top of this unit, at the depth of 80-90 cm. The soil is dated at 2740±70 BP (Ki-10281). The structureless sediments deposited above the fossil soil originated from intensified soil erosion after forest clearance. Their sorting is worse due to admixtures of silt and clay. Organic matter content is 2.5-3%, and up to 3.5% in layers enriched with humus at the depth of 60-70 cm. This humus-rich layer was dated at 3160±90BP (Ki-7962) which produced the inversion in comparison with the fossil soil horizon occurring underneath. The dated humus-rich layer has the highest electrical conductivity, even higher than the contemporary tillage horizon. This can be explained by high content of humus, clay fractions and colloidal substances derived from the erosion of the upper parts of the slope. The enrichment in fine material is also

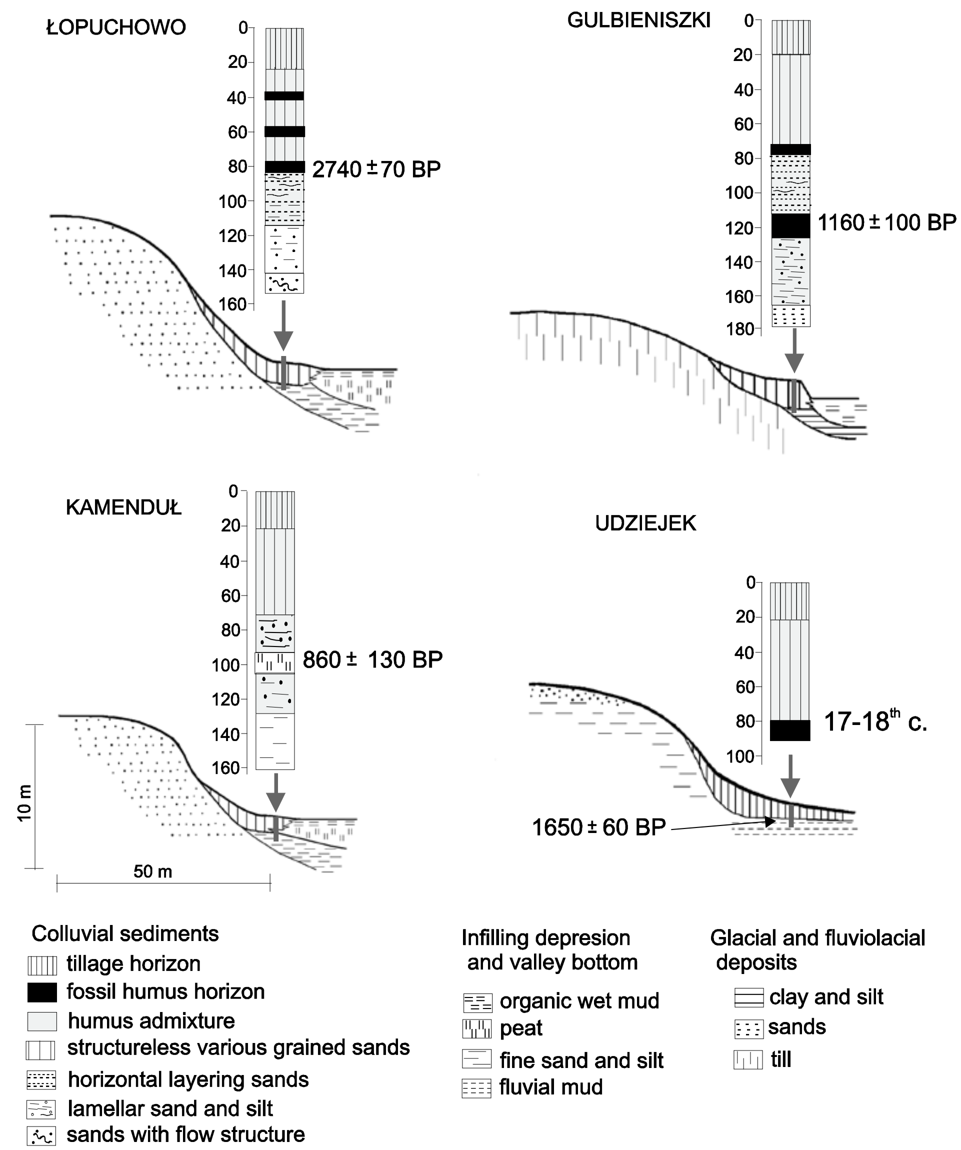

Fig. 2. *Selected slope profiles and colluvial deposits at footslopes*

reflected in granulometric indices – the mean grain size diameter Mz=2.8 phi and the worst sorting σ_1=0.8 (apart from the tillage horizon).

A content of heavy minerals within the footslope deposits was analysed at the Łopuchowo site (**Fig. 4A**). The layer of inverted age (3160±90 BP, Ki-7962) has an abundance of mica (12%) and amphiboles (28%) and a significant share of pyroxenes (3.5%) in comparison with the layer dated at 2740±70 BP (Ki-10281), having the share of the same minerals: 9.8%, 24% and 5% respectively. Micas are easily mobilized and transported due their lamellar structure, therefore relative abundance of micas is characteristic of the depositional zone (Racinowski, 1974, Florek *et al.*, 1987, 1990; Mycielska-Dowgiałło, 1995, 1999). Amphiboles are resistant to mechanical abrasion but not for chemical weathering, therefore these minerals are poorly represented in soil horizons (Konecka-Betley and Majsterkiewicz, 1973; Kuźnicki *et al.*, 1974; Cichosz-Kostecka *et al.*, 1991). Therefore, the higher number of amphiboles in the layer of inverted age can be interpreted as a result of a limited action of soil forming processes. Pyroxenes are also not resistant to chemical weathering; they differ from amphiboles in slightly higher resistance to abrasion. When analyzing processes of transport and deposition, one should take into consideration the proportion between amphiboles and pyroxenes. Lower values of the A/P index, the number of amphiboles divided by the number of pyroxenes, are typical for fossil soil horizons found within dunes (Barczuk and Mycielska-Dowgiałło, 2001). Apparently, this index can be also used in the analysis of the colluvial deposits. It attains lowest values in the lower

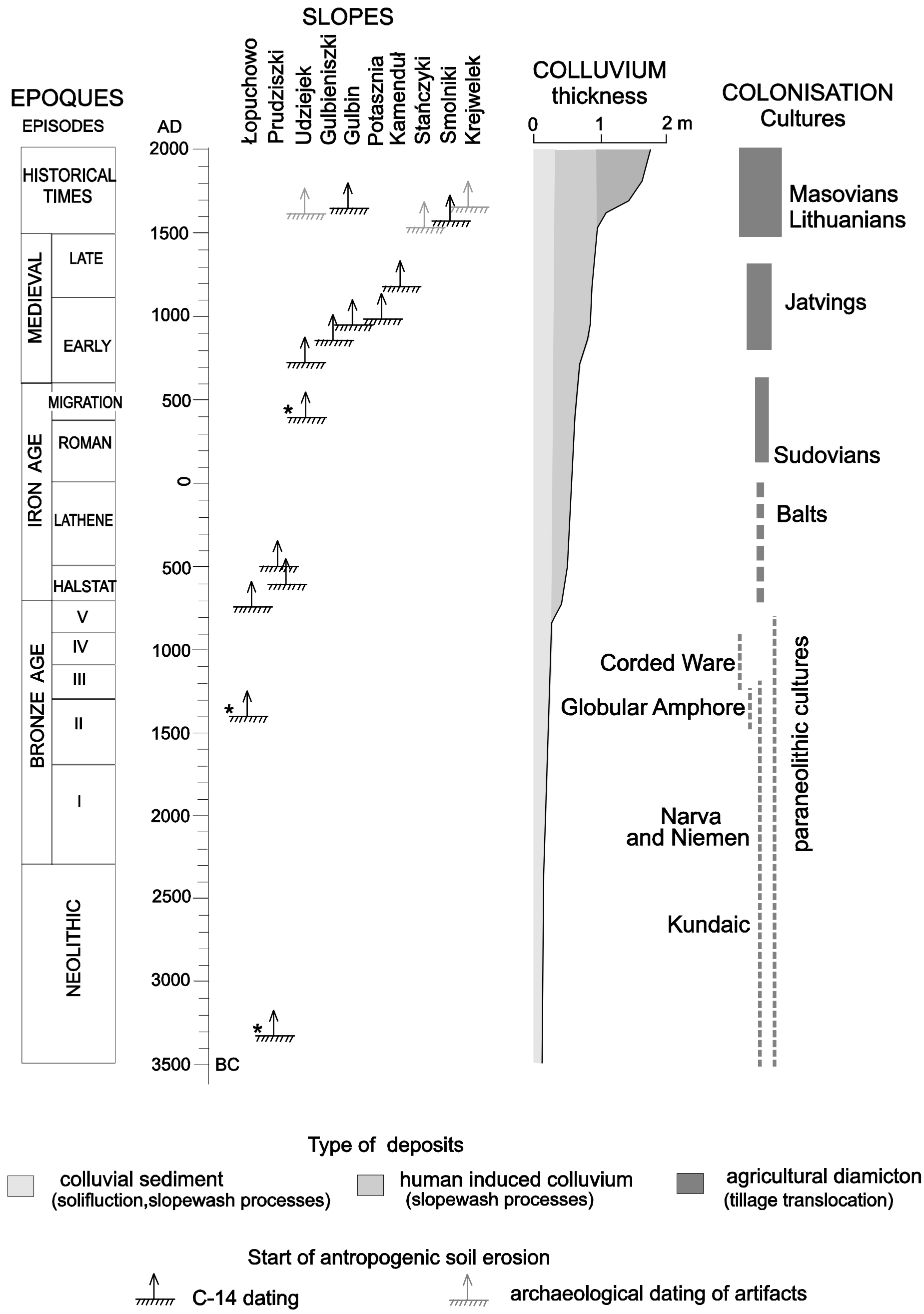

Fig. 3. *Comparison of the age and thickness of anthropogenic colluvial sediments with colonisation phases of Suwałki Lakeland according to regional scale (Kaczanowski and Kozłowski, 1998; Brzozowski* et al.*, 1993, Bitner-Wróblewska, 1998); (*discussed age of colluvium)*

humus horizon (dated 2740±70BP, Ki-10281). On the other hand, the value of this index calculated for the layer of the inverted age is not outstanding (**Fig. 4A**).

Complex analysis of the sedimentological features (granulometry and heavy minerals content) allows to determine phases of slope stabilisation and aggradation in cases where fossil humus horizons are similar and the colluvial deposits do not differ when examined in the filed.

Prudziszki – degradation process recorded in the deposits

A case from the Prudziszki site was selected in order to show how the degradation process is recorded within the deposits. At this site, peat found under colluvium is dated at 5405±80 BP (Ki-10280, **Fig. 4B**), which is an extraordinary old age and completely does not correlate with archaeological data, since the first farmers arrived to the study area much later. Age of the peat neither agrees

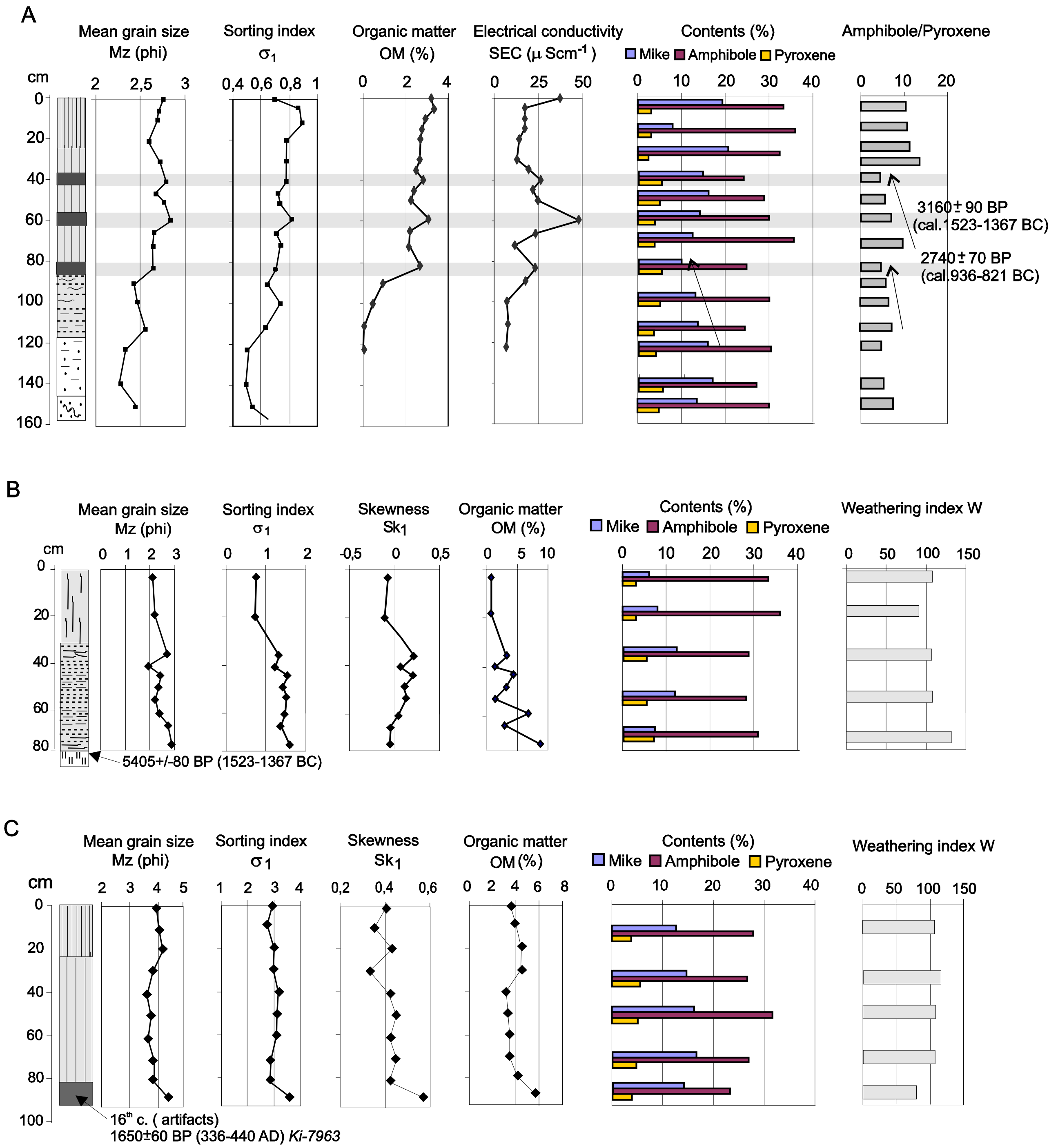

Fig. 4. *Chosen sediment characteristics at vertical colluvium profiles: Łopuchowo (A) Prudziszki (B) and Udziejek (C); arrows show weathering-depositional cycles; lithology explanation in* ***Fig. 2****.*

with palynological data, because sediments of such age do not contain crop pollen (Stasiak 1965, 1971; Kupryjanowicz, 2004, 2007). The lower part of the colluvium deposited at the footslope is characterised by lightly higher organic matter content and finer fraction which is reflected in Mz (attaining higher value in the phi scale). The only untypical feature for the fossil soil horizon is a slightly negative skewness. It can be inferred that the lower part of the colluvium is not a typical soil horizon, despite its apparent similarity to hydromorphic soils (black soils).

The analysis of heavy minerals, with a special focus on the resistant minerals, is often used in inferring about the weathering processes (Mycielska-Dowgiałło, 1995, 1999). Shares of minerals of different resistance to mechanical and chemical weathering are compared with each other and a weathering index (*W*) is calculated. Racinowski and Rzechowski (1969) determined the value of the weathering index based on glacial tills of different age and described it as follows:

$$W = St \cdot \frac{N}{T} \tag{4.1}$$

where *N* is the percentage share of not resistant minerals, *St* – the share of minerals of moderate resistance, *T* – the share of resistant minerals. This index was also used for fossil soil horizons found within the dune sediments (Konecka-Betley and Majsterkiewicz, 1973; Cichosz-Kostecka *et al.,* 1991; Dzierwa and Mycielska-Dowgiałło, 2003). Lower values of *W* indicate chemical weathering, high values indicate mechanical weathering (abrasion). The value of the weathering index calculated for the colluvium at Prudziszki varies between 95 and 135 (**Fig. 4B**). In the lowermost part of the deposits, it attains the highest value (135), indicating mechanical erosion (abrasion due to transportation along the slope profile). Probably, the uppermost part of the underlying peat was eroded and therefore the extraordinary old age of the peat, older then the beginning of the Balts settlement in the area (at 8^{th} century BC), can be understood.

Udziejek – sedimentary record of soil weathering

Sometimes, in a single colluvial layer archaeological artefacts of different age can be found. Such artefacts could have been transported from the whole micro-catchment area. In such cases, age of the youngest artefacts serve as an indicator of the time of colluvium deposition. Such a situation occurs in Udziejek where the whole colluvial deposits are structureless and homogenous, only their lowermost part is enriched in humus (**Fig. 2**). Artefacts of a diversified age (from Neolith up to the New Era times) were found within the deposits. The radiocarbon age of the lowermost part of the deposits is 1650±60 BP (Ki-7963). On the other hand, the youngest archaeological artefacts show significantly younger age of the colluvium (16^{th} century AD).

Granulometric composition and content of heavy minerals in the vertical profile of the colluvium in Udziejek is shown in **Fig. 4C**. Weak sorting of the lowermost part of the colluvium and significantly positive skewness are indicative of aggradation processes. Low value of the weathering index (*W*=75) usually testify for a long-lasting (slow) soil forming process. Very small share of amphiboles (23%) can be interpreted as a remnant of an older soil horizon, developed before the cultivation of the slope. Tillage of the slope leads to mixing of the previous soil with younger slope deposits and creation of the mixed colluvium. The radiocarbon age probably shows the real date of start of denudation triggered by human action. This is supported by archaeological artefacts from the Balts and the Jadvings cultures found in other places near the researched slope in Udziejek (Brzozowski *et al.,* 1993).

5. CONCLUSIONS

Denudation triggered by the human action is a very dynamic process, and studies of late-Holocene deposits must take into account the settlement history of the area. Radiocarbon age of the colluvium originated from enhanced erosion sometimes does not correlate with archaeological data. This research on granulometric features and heavy minerals was focused on colluvial layers enriched in humus in three different situations: 1) occurrence of inverted age of the humus rich layers - record of aggradation process in sediment, 2) radiocarbon age being older then archaeological evidence – record of erosion process, and 3) record of older fossil soil transformed during younger phase of colonisation. It is found that analyses of sedimentological features of colluvium such as: share of fine fraction (or the mean grain size diameter), sorting, skewness, and organic matter content are useful tools in reconstruction of soil erosion phases. Electrical conductivity and content of heavy minerals determined for selected soil horizons allows inferring about degradation and agradation processes and therefore help in a proper selection of samples for dating. Sedimentological features of the deposits can be also used in reconstructing phases of slope erosion in places where archaeological dating is missing.

ACKNOWLEDGEMENTS

I would like to thank Prof. Elżbieta Mycielska-Dowgiałło and Prof. Andrzej Barczuk for a discussion on interpretation of heavy minerals analysis.

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