The origin and evolution of small dry valleys in the last-glacial area on the example of the Pomeranian Lake District (Poland)

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Abstract. Short dry valleys forming a part of the relief characteristic of the temperate zone occur particularly frequently in areas related to the young-glacial zone. Two areas were selected for analysis – Piaski Pomorskie and Jasień, located in northern Poland, at the back of the Pomeranian phase of the Vistulian glaciation. The aim of the research was to determine the role of denudation processes in the landform transformation of the young-glacial areas, manifested in their cutting and creation of, among others, erosional-denudational valleys, and to compare their geomorphological features. The research included field work (recognition of the geological structure, levelling measurements) and laboratory work (grain size analysis, organic matter content, age determination of the deposits). The valleys from both areas vary in size, but have a similar structure of deposits on their bottoms and at the outlets. Within the bottoms of the valleys, the erosively dissected fossil surfaces of the fluvioglacial substrate are visible or there is an erosional pavement. Slope deposits were found in all the valleys, mainly in the form of massive sand or sand and silt series. Their youngest, topmost part lies on organic sediments dated to 81 (95.4%) 253 cal. AD and 1024 (95.4%) 1224 cal. AD. The most distinct difference in the structure of the valleys of both research fields is the presence of boulder levels only in the Jasień area. This may suggest that the genesis of boulder covers depends not only on climatic and plant conditions, which were similar in both areas, but also on the geological structure and morphometry of the valleys.

The obtained results indicate that the valley development was dominated by linear erosion in the Bølling and Allerød, mass movements mainly in the cold stage of the late Vistulian and slopewash, which were especially strong in prehistoric and historic times. The differentiation in the size of valleys only to some extent affects their geological structure and processes that accompanied their evolution.

Key words: erosional-denudational valleys, young-glacial area, landform transformation, late glacial, Holocene, northern Poland.

INTRODUCTION

Dry erosional-denudational valleys, as well as denudational basins, are most often the subject of research concerning the evolution of the terrain relief in the late Vistulian and Holocene. In recent decades, dry valleys have been studied mainly in terms of morpholithology, morphogenetics and morphodynamics (e.g. Gołębiewski 1981; Marsz 1995; Twardy 1995; Sinkiewicz 1998; Wilkinson 2003; Smolska 2007; Majewski 2013; Paluszkiewicz 2016). Nowadays, issues related to determining the magnitude of the impact of economic activity on the evolution of the existing valleys and the emergence of new erosive forms in the Holocene are particularly often addressed (e.g. Larue 2002; Wilkinson 2003; Belyaev et al. 2005; Smolska 2007, 2011; Panin et al. 2009; Twardy 2009; Ionita 2011; Schmidt & Heinrich 2011; Soms 2011; Kittel 2014; Majewski 2014; Larsen et al. 2016).

The fundamental evolution of the Polish Lowland relief north of the Pomeranian Stage of the Vistulian glaciation (PSV) took place in the late glacial and early Holocene (Kozarski 1995; Starkel 2005). It was the time when climatic and hydrological conditions favoured the emergence of dry valley forms in central Europe (e.g. Klatkowa 1965; Maruszczak 1968; Gołębiewski 1981; Churska 1989; Marsz 1998; Larsen et al. 2013; Majewski 2013; Paluszkiewicz 2016; Woronko et al. 2018). In the Holocene, the transformations of the relief, including the already shaped valleys, were often only retouching and related mainly to human economic activity which led to an increase in denudation (Lang 2003; Smolska 2007; Szwarczewski 2009; Twardy et al. 2011). Research works conducted in recent years show that dry valleys and/or ravines could have been formed in the Holocene in temperate forest areas even without human impact (e.g. Belyaev et al. 2005; Panin et al. 2011; Soms 2011).

Forms of dry valleys are common in the old-glacial area of the Polish Lowlands and constitute an indicative feature in the development of land relief (Klatkowa 1965; Rotnicki 1966; Twardy 1995, 2005). The young-glacial relief of the Polish Lowland and neighbouring areas is still little known, hence it seems reasonable to try to explain the morphogenesis of the areas north of the Pomeranian Stage of the Vistulian glaciation. In addition, dry valleys can be a source of palaeoenvironmental information which further increases the purposefulness of the research.

The main problem addressed in this article is determining the role of small dry valleys in the relief transformation of young-glacial areas, their genesis and evolution based on sediments and accumulation cones accompanying them. The geological structure of sediments of the valleys in two research areas was compared and their morphometric parameters were determined. In order to obtain a more complete picture of the problem analysed, valleys with strongly differentiated morphometric traits were selected for the study.

RESEARCH AREA

The research was carried out in the early post-glacial zone of the Polish Lowland shaped on the foreland of the glacier, which retreated from the outreach line of the Pomeranian phase of the Vistulian glaciation of approximately 16.2 ka BP (Kozarski 1995). Two test areas located at the back of the glacier of the Pomeranian Stage were selected for detailed research: I – the upland edge of Piaski Pomorskie (53°45′N, 16°14′E) and II – the slopes of the Lake Jasień tunnel (54°18′N, 17°38′E) (Fig. 1).

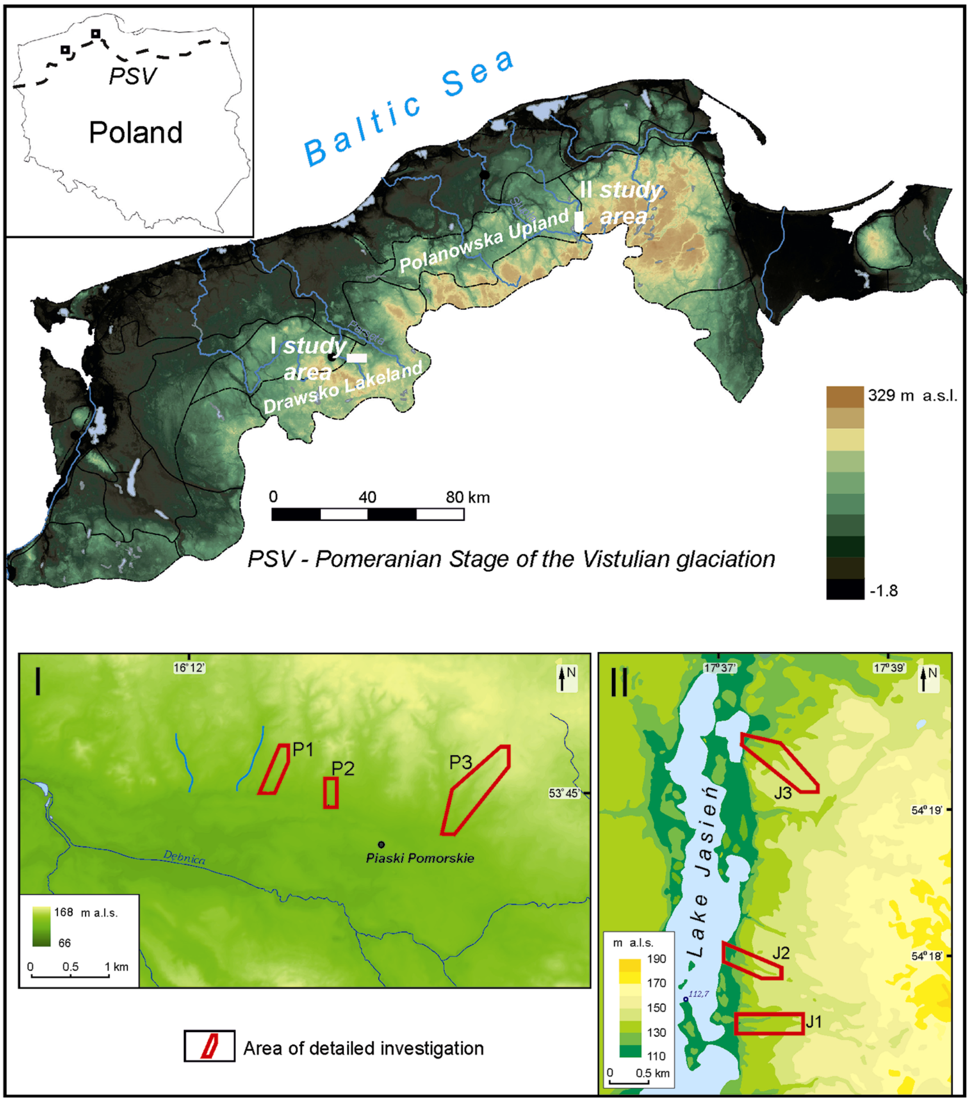

Fig. 1. Location of the survey area: I – Piaski Pomorskie test area; II – Jasień test area.

The predominating element of the Piaski Pomorskie test area is the moraine upland plateau. The upland W–E edge of the Piaski Pomorskie region stretches across the length of about 6 km. Thirty erosional-denudational valleys with the N–S course, which are clearly visible in the landscape, were distinguished within it. However, the accumulation cones, associated with the valleys, are less clearly represented in the landscape (Paluszkiewicz 2013, 2016). The absolute heights of the area range from 100 to 125 m above sea level (a.s.l.). The northern part of the edge is made of glacial gravel-silty sands. The middle parts of the valleys cut surfaces made of boulder clays, while the lower sections are cut into a series of sands with fluvioglacial gravels.

The research in the tunnel of Lake Jasień covered its eastern slope, which rises to 170 m a.s.l. The shoreline of Lake Jasień is accompanied by lake-side terraces, the ordinates of which do not exceed 115 m a.s.l. On their surfaces there are alluvial fans associated with erosional-denudational valleys. Two sandur levels (Florek et al. 1999) adjoin directly the flattening, reaching the ordinate up to 140 m a.s.l. An upland moraine plateau stretches above these sandur levels. The landscape of sandurs as well as of uplands is enriched in numerous landlocked depressions and erosional-denudational valleys showing a perpendicular course to the longitudinal axis of the lake.

RESEARCH METHODS

In order to clarify the presented research problem, field and laboratory tests were carried out. During field work, exposures and manual drilling were performed within the bottoms and lower parts of the valley slopes as well as accumulation cones in order to identify the lithology. Specimens for laboratory analysis were taken from the exposures. The levelling measurements were made, on the basis of which longitudinal and transverse profiles were drawn and the morphometric parameters of the valleys were calculated (Table 1).

As part of the laboratory tests, the granulometric composition of the substrate sediments and slope series were determined. The dry sieve method was used to analyse the grain size. For samples with the share of silt-clay fraction above 12%, sieving and the aerometric method, modified by Prószyński (Dzięciołowski et al. 1980), were used. The mean grain diameter (Mz) and the standard deviation (σ_1) were calculated according to Folk and Ward formulas (1957). The content of organic matter was determined by loss on ignition (LOI) at a temperature of 550 °C. For five samples, the absolute age was determined using the ^{14}C dating method at the Laboratory of the Archaeological and Ethnographic Museum in Łódź and the ^{14}C AMS Laboratory in Poznań.

RESULTS

Morphometric analysis of erosional-denudational valleys

The P1 valley is a form with a length of 196 m (Fig. 1, Table 1). The inclination of the valley bottom is not very diverse and is a reflection of the inclination angle of the terrain surface in which the form was created. In the upper section, where the depth of the form does not exceed 2 m and the width 1.5 m, the valley slopes

Table 1. Morphometric characteristics of the examined valleys

Valley	Catchment area (ha)	Max/min elevation (m a.s.l.)	Length of the valley (m)	Max/min width (m)	Average inclination of the valley bottom (°)	Maximum inclination of the slopes and their exposition (°)
P1	17.1	111.2/94.8	196	14.6/4	3.8	25.2 NW 22.3 SE
P2	3.1	97.1/87.8	110	6.6/1.6	2.8	22.1 SW 25.1 NE
P3	59.8	107.6/96.2	377	5.7/2.9	1.0	24.5 NW 28.1 SE
J1	28.4	140.5 (155)/118.5	900 (1445)	81.0/36	1.5	22.3 N 17.7 S
J2	30.8	140.0/114	675	58.0/26	2.1	15.4 NE 14.1 SSW
J3	27.8	144.5/115	1190	80.0/52	1.8	14.9 N 14.2 S

are symmetrical and their inclination is 13.5°. Higher diversification in slope inclination was observed in the middle course of the valley (Table 1). The depth of the form reaches 4 m. The width of the valley bottom along its entire length is quite diverse and changes from 4 m in the upper and middle course to over 14 m in the mouth section (Fig. 2A).

The P2 valley is located approximately 0.5 km to the east of the P1 form (Fig. 1, Table 1). The length of its bottom is 110 m. The profile of the elongated form is varied – the fall of the valley bottom is 6.4° in the upper part and 4.8° in the middle and lower parts. The depth of incision varies from 1 m in the upper section to 4 m in the middle section of the valley. An accumulation cone occurs at the outlet of the form.

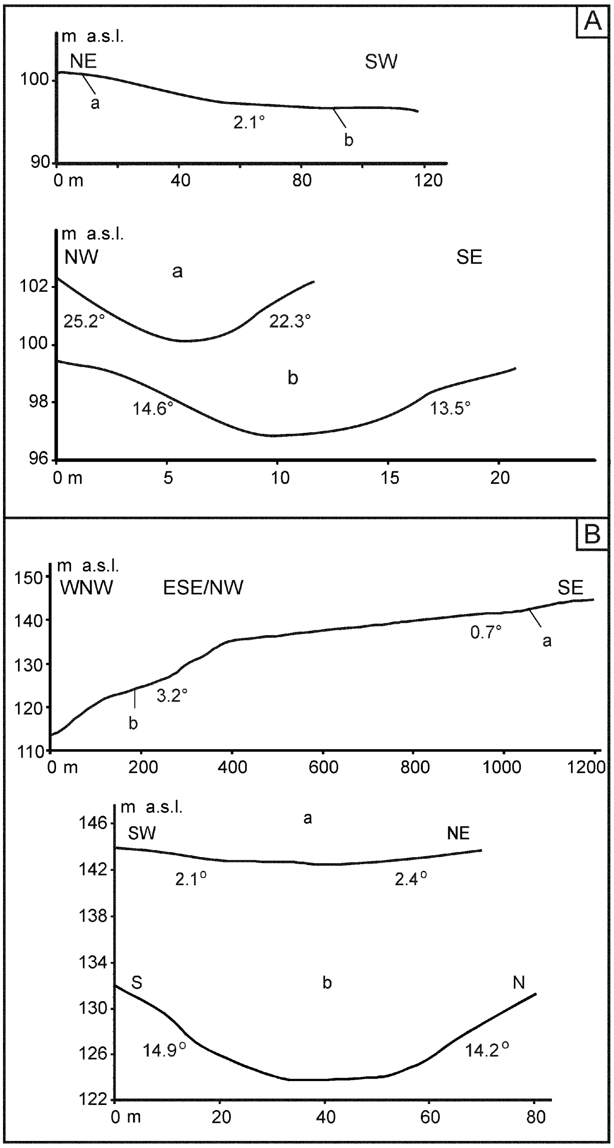

Fig. 2. Morphological profiles of example valleys: **A,** upper and middle parts of the P1 valley; **B,** upper and lower parts of the J3 valley.

The P3 valley is located in the eastern part of the upland edge, at a distance of 1.5 km from the P2 valley (Fig. 1). Being 377 m long, it is one of the longer forms of this area (Table 1). The slope inclination shows slight asymmetry: SE slopes have a slightly higher inclination than NW slopes (SE 28.1°, NW 24.5°). The middle part of the form shows the largest indentation, reaching up to 6 m in depth.

The J1 valley is located in the southern part of the Jasień area (Fig. 1). The main part of the form reaches a length of nearly 900 m (Table 1). In the upper part, the form has a depth of 2–3 m and the slopes are inclined at an angle of 4°–6°. The maximum width does not exceed 70 m here. In the lower course of the form, the width increases to 80 m, the depth reaches 10 m and the slope inclination varies from 14° to 18°.

The J2 valley is located 700 m north of the J1 form (Fig. 1). The length of the valley does not exceed 700 m (Table 1). In the upper section, the valley is shallow – up to 2–3 m and very narrow with a width of about 25 m and its cross profile is pan-shaped with a noticeable delicate cutting in the axial part. In the lower part of the valley its bottom becomes flat and is clearly distinguishable from the slopes, which are inclined here at an angle of about 13°–15°. The depth of the form reaches 5 m and its width does not exceed 50 m.

The J3 valley is located in the northern part of the Jasień area (Fig. 1). Its length is nearly 1200 m (Table 1). In the upper and middle sections, the valley cuts the slightly sloping surface of the sandur, which translates into the roughness of its cross-section profile – slopes incline at an angle of 2°–4°, the inclination of the bottom does not exceed 1° and its depth is 2–3 m with the width of about 70 m. In the lower section, the form is clearly marked in the landscape, which is the result of cutting here the steep sides of the lake tunnel. The width of the valley reaches 80 m with the depth of 8 m. The slopes are inclined at an angle of 14°–15° and the bottom is wide and flat, inclined at an angle of more than 3° (Fig. 2B). At the mouth of the valley there is a small accumulation cone.

Characteristics of the geological structure of erosional-denudational valleys

The geological structure of the P1 valley was determined in its central part. Sediments of the floor are represented by fluvioglacial fine-grained sands (Mz = 2.23 phi, σ_1 = 0.94 phi) and medium-grained sands (Mz = 1.88 phi), divided by a thin layer of very poorly sorted coarse silt (Mz = 5.04 phi, σ_1 = 3.86 phi). This series reaches a thickness of 1.5 m. In its topmost part, at a depth of

2.5 m, there is a boulder layer (erosional pavement), which may indicate the depth of the former valley bottom. The boulder layer is overlain by colluvial deposits – massive fine-grained sands, moderately sorted (Mz = 2.20–2.48 phi, σ_1 = 0.81–0.97 phi).

The geological structure of the P2 valley was recognized in its upper part. In the upper section, the sediments of the substrate are fluvioglacial fine-grained sands of massive structure. These deposits were observed at a depth of 1–2.2 m below surface. The gravel–boulder level above them is interpreted as a layer of erosional pavement (the former valley bottom). The topmost part contains a series of colluvial massive fine-grained sands with a thickness of 0.5 m. An accumulation cone occurs in the lower part of the valley. In the proximal part of the cone, the floor consists of massive fine-grained sands (Mz = 2.45 phi, σ_1 = 1.22 phi), in the topmost part lined with medium-grained sands with gravel (Fig. 3A). The thickness of the series is 2 m. In the distal part of the cone from a depth of 1 m, a 2.7 m thick layer of peat is found, in the topmost part lined with inserts of grey fine-grained sand (Fig. 3B). The share of organic matter in peats was 80%.

The geological structure of the P3 valley was studied in its central part to a depth of 2.5 m. The substrate consists of coarse sands with poorly sorted gravel (Mz = 0.85 phi, σ_1 = 1.48 phi). In the western part of the edge of the valley slope, the sediment ceiling is located at a depth of 2 m, while within the bottom these sediments lie directly below the surface. At a depth of 0.55 m there is a zone of erosional pavement indicating the former bottom of the valley. Colluvial sediments occur on the slopes of the valley and are represented by deposits of coarse silt and poorly sorted fine sand.

The geological structure within the J1 valley looks as follows. The substrate that the valley cuts is made of fluvioglacial variegated sands, which create a sandur here (Majewski 2013), and their top lies at depths from 0.7 to 1.8 m. The fluvioglacial series is overlain by a 20–25 cm thick slope boulder–sand series with a small admixture of gravels. It occurs at the bottom of the form and at the southern slope. The series located at the boulder–sand level is represented by variegated sands (Mz = 1.6–2.9 phi), which are poorly sorted (σ_1 = 1.2 phi), with a thickness of 0.3–1.2 m. The shape of their ceiling refers to the shape of the contemporary surface of the bottom and lower parts of the slopes. The series is covered with 0.25–0.35 m thick colluvial sands, most likely originating from soil erosion sands, with a high share of humus.

In the J2 valley, the substratum of the slope series of different types consists of fluvioglacial variegated sands (series a in Fig. 4). Their ceiling creates a surface that resembles the shape of the transverse profile of the valley and is located at a depth of 1–1.2 m with visible traces of cutting the surface. The series located on the substrate consists of sand–gravel sediments (b) (Mz = –0.85–0.7 phi), which are poorly and very poorly

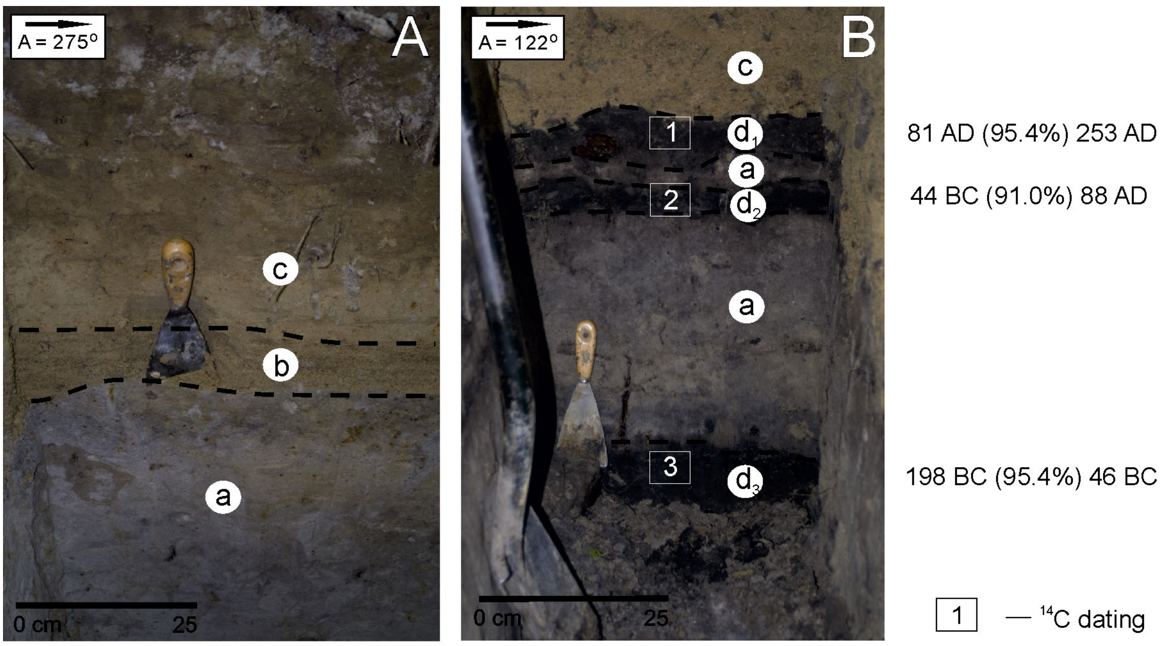

Fig. 3. Deposits of the proximal (**A**) and distal (**B**) parts of the cone located at the mouth of the P2 valley: a, fine-grained sands; b, medium-grained sands with gravel; c, fine-grained sands; d_1, d_2, d_3, peat.

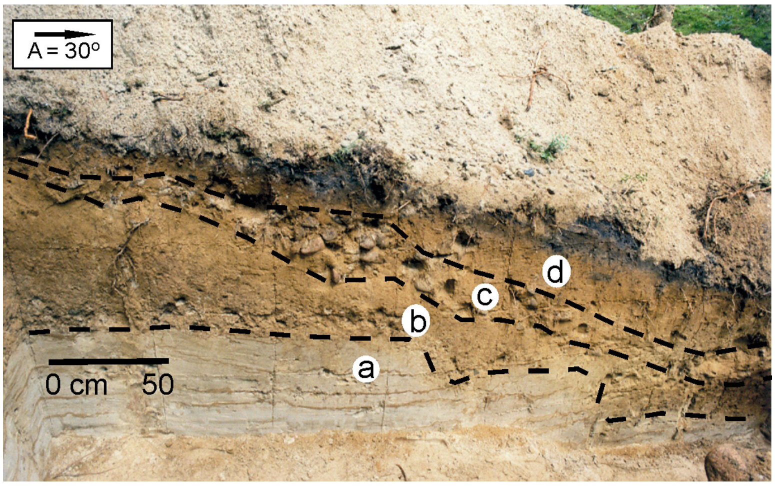

Fig. 4. Geological structure of the slope and a fragment of the bottom of the J2 valley: a, fluvioglacial sediments of the substrate; b, sand and gravel deposits; c, boulder level; d, sands with an admixture of gravels.

sorted (σ_1 = 1.45–2.4 phi), with a thickness of up to 0.5 m, whereas heavily weathered gravels occur in the floor. The next layer visible along the entire cross section is the boulder level (c). Its thickness ranges from a few centimetres to nearly 0.50 m. An important feature of this layer is its inclination referring to the inclination of the valley slopes, and the topographic position similar to the position of the boulder–sand series recognized in the J1 valley. On the boulder level there is a poorly sorted sandy colluvia with an admixture of gravel (Mz = 0.97–1.52 phi; σ_1 = 1.2–1.85 phi) (d). Their thickness ranges from a few centimetres to about 0.8 m.

In the lower section of the J3 valley, the topmost part of the fluvioglacial substrate occurs at a depth of 2 m. It is overlain by a gravel–sand–boulder level (series a in Fig. 5) that is considered to be a late-Vistulian erosional pavement (Majewski 2013). The next sedimentation series is represented by colluvial sands (b) with a small admixture of gravel (Mz = 0.92–1.11 phi; σ_1 = 1.4–1.7 phi). The thickness of the series is 0.45 m. The sand–gravel series transforms towards the surface into a series of colluvial medium sands with an admixture of coarse sand (c), within which the fossil red soil and the fossil podzolic soil are visible (d). Its topmost part lies at a depth of 0.5–0.85 m, forming the late Holocene fossil bottom of the valley. The lowest deposits (e) consist of poorly sorted sand and silt colluvia (Mz = 2.1–2.6; σ_1 = 1.3–1.45 phi) with an organic matter content of 5–7% and a thickness of up to 0.85 m. They fill the fossil cavity, at the bottom of which charcoal pieces were found that were dated to 1024 (95.4%) 1224 cal AD (LOD-1429) (Fig. 5, Table 2).

The bottom of the valley is adjoined by a cone. In its proximal part, the thickness of slope sediments is 2.2 m.

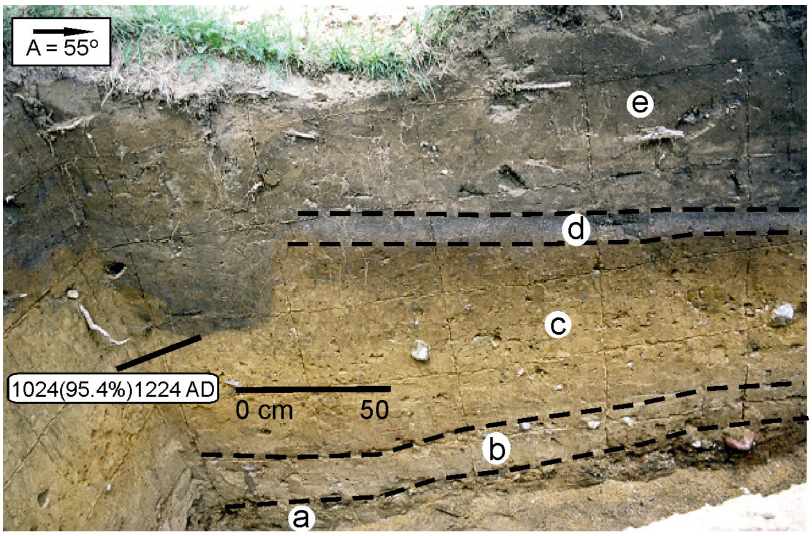

Fig. 5. Geological structure of the bottom of the J3 valley: a, gravel–sand–boulder level; b, sand with an admixture of gravels; c, medium-grained and coarse sands; d, fossil podzolic soil; e, sand and silt deposits.

Table 2. Sample description with conventional and calibrated ages of the samples

Sample description	Lab. code	^{14}C age (BP)	Age range (95.4%) [a)]	Depth below surface (m)	Material of sample
P-2/d_3	Poz-22990	2100 ± 30	198–46 cal. BC	1.60–1.64	Peat
P-2/d_2	Poz-229910	1965 ± 35	44 BC–88 AD (91.0%)	1.26–1.30	Peat
P-2/d_1	Poz-22992	1835 ± 35	81–253 AD	1.10–1.14	Peat
J-3	LOD-1429	900 ± 50	1024–1224 cal. AD	1.05–1.10	Charcoal
J-3/o-1	LOD-1430	8270 ± 80	7496–7082 cal. BC	2.08–2.18	Detritus gyttja

[a)] Oxford program OxCal v4.2.4 Bronk Ramsey and Lee (2013).

DISCUSSION

Detailed study of the geomorphological features of the valleys made it possible to determine the similarities and differences in their structure. These dependencies may result from different morphometric parameters of the forms. The dissections of the Jasień area are much longer and wider than the forms of the Piaski Pomorskie edge zone (Table 1). The longest valley of the Jasień area is 1400 m, that of Piaski Pomorskie less than 380 m. This is conditioned by the length of the slopes of the Lake Jasień tunnel amounting to 1500 m, while the slope of the upland of the Piaski Pomorskie area reaches a length of about 200 m. In addition, the valley slopes in the Piaski Pomorskie area have a much greater inclination angle than those of the Jasień area (Table 1). In both areas the greatest inclination occurs in the middle, less often in the lower part of their run. No clear asymmetry of the slopes was found in the tested forms. It should be added that all valleys have a flat and wide bottom in the lower section (the effect of the accumulation of sediments associated with flow along the axis) and in the upper part close to the concave one.

Both groups of valleys developed on the fluvioglacial basis. The erosional pavement was recognized in all valleys of the Piaski Pomorskie area, but only in the J3 valley in the Jasień area. The authors associate the formation of the pavement with erosion phases involving the bottoms of periglacial dry valleys, which could have happened in the Bølling and Allerød (Majewski 2013; Paluszkiewicz 2016). This is in line with the views on the stages of erosion within the bottoms of dry valleys in the Bølling (Marsz 1964; Klatkowa 1965) and Allerød (Maruszczak 1968; Marsz 1995). The increase in erosion intensity was caused by intensive flow of periodic waters originating mainly from the melting of long-term permafrost and dead ice cubes (Błaszkiewicz 2005, 2011; van Loon et al. 2012; Kobojek 2014). Hampered water infiltration because of a long-term permafrost in the ground in northern Poland throughout the Bølling (Kozarski & Nowaczyk 1995) and an increase in the amount of precipitation (Peyron et al. 2005) favoured the cutting of the area surface. The process of cutting the bottoms of the valleys intensified in the Allerød due to the increase in humidity (Goslar et al. 1999; Vielichko et al. 2002).

On the other hand, confirmation that the valley bottoms were cut at the end of the late Vistulian and possibly also at the beginning of the Holocene was recognized at the mouth of the J3 valley. The deposits building the cone accumulate on gyttja, the ceiling of which was dated to 7496 (95.4%) 7082 cal. BC (LOD-1430) (Fig. 6, Table 2).

The lack of the erosional pavement in the valleys J1 and J2, which may result from the slight inclination of the bottoms of these forms, is noteworthy (Table 1). In these valleys, erosion was recorded in the form of fluvioglacial dissection of the substrate. However, the erosive pavement present in the J3 valley could have developed due to the large area of the valley basin and significant inclination of its bottom in the lower section, which promoted intense erosion.

In analysing the geological structure, attention was paid to the boulder levels, which were observed only in the valleys of the Jasień area (valleys J1 and J2). These series are associated with gravitational displacement on the slope in the cold periods of the late Vistulian (Churska 1989; Marsz 1998; Majewski 2013). This could have been favoured by the growth of long-term permafrost in the younger Dryas (Hoek 2001; Renssen & Vandenberghe 2003). Lack of this sedimentary series in the valleys of the Piaski Pomorskie area may be conditioned by the geological structure and the small size of the forms, which could have influenced the intensity of gravitational slope processes.

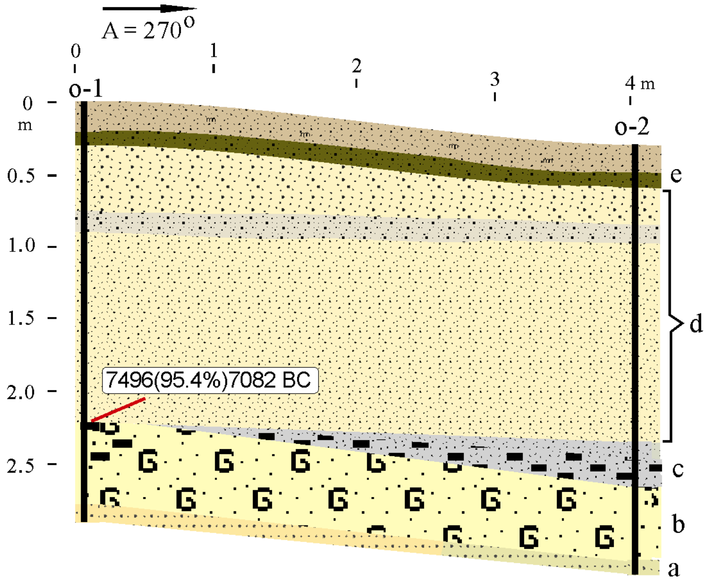

Fig. 6. Geological structure of the proximal part of the J3 valley cone: a, fluvioglacial sediments of the ground; b, gyttja; c, sandy peat; d, sand and gravel deposits; e, sand and silt deposits.

As indicated by the massive character of slope sediments, the slopes were destroyed by mass movements (mainly creeping). The valleys have similarly well-formed shallow series of slope sediments in the form of sandy colluvia. The floor part of it may originate from the late Vistulian and Holocene, the period when the succession of forests (Ralska-Jasiewiczowa 1999) could not keep up with fast climate changes, and thus the material could have been washed out of the slopes of the already developed valleys (Larsen et al. 2013, 2016). This is confirmed by the situation diagnosed in the J3 valley, where the late Vistulian pavement was covered with colluvia and Holocene fossil humus horizons (Fig. 5).

The topmost parts of the colluvia, often consisting of sands and silts, come from the youngest part of the Holocene – the Subatlantic. This regularity was recognized within the forms of both compared areas. Within the P2 valley cone, the peat ceiling dated to 81 (95.4%) 253 cal. AD (Poz-22992) is covered with an about 1.1 m thick conical series (Fig. 2B, Table 2). In the J3 valley, however, the nearly 1 m thick colluvia are covered with charcoal of the age of 1024 (95.4%) 1224 cal. AD (LOD-1429) (Fig. 5, Table 2). In both cases the formation of the colluvia is associated with the increase in the intensity of the slope processes caused by the development of economic human activity (firing and grubbing of forest areas, cultivation of land). The increased share of organic matter in these sediments indicates water erosion from the humus horizon of soil higher on the slope.

The accumulation cones occur only of the J3 and P2 valleys. In the case of other forms, a significant part of the eroded material was delivered to the valley of the Dębnica River (forms P1, P3) and Lake Jasień (forms J1, J2).

No slope sediments from the boreal-subboreal period were identified within the studied forms. This indicates the disappearance of mechanical denudation at that time and is consistent with the results obtained for other areas of Central Europe (e.g. Borówka 1992; Sinkiewicz 1998; Twardy 2000; Zolitschaka et al. 2003; Smolska 2007; Majewski 2014).

CONCLUSIONS

The studied erosional-denudational valleys developed at the turn of the late glacial and the Holocene in similar climatic and plant conditions. Nevertheless, they are clearly characterized by different values of morphometric parameters, which indicate a different degree of transformation of the landscape. The valleys in the area of Piaski Pomorskie are much shorter and have steeper slopes than the forms of the Jasień area. This is due to the morphometric differences of the areas they cut – the hillslope of the moraine plateau of Piaski Pomorskie is short and steep, while the edge zone of Jasień Lake is longer and gentler.

Similar sedimentary series were identified in the structure of the valleys, indicating the dominant morphogenic processes responsible for their formation. Within the P1, P2, P3 and J3 valleys, the level of erosional pavement was detected, the presence of which indicates the essential role of linear erosion processes in the formation and development of forms. The erosion effects are also visible in the structure of the J1 and J2 valleys where the erosively cut substrate can be seen. Massive sand and sandy silt in the bottoms of all forms represent the colluvial deposits originating from creeping and water erosion, indicating the significant role of creeping and slopewash. The boulder levels, characteristic only of the Jasień area, may suggest that their genesis depends not only on climatic and plant conditions but also on the geological structure and morphometry of the valleys. The topmost parts of the sediments that fill up the valleys represent the colluvia. They were recognized on both research stands and are the result of economic activity of man in prehistoric and historical times. Depending on local topographic conditions, cones at the mouth of valleys may be clearly developed or practically not marked in the landscape.

The presented results indicate that the development of the valleys was dominated by linear erosion (Bølling and Allerød), mass movements (mainly in the cool stage of the late Vistulian) and slopewash which intensified in the Subatlantic in connection with the economic activity of man.

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Erosioonilised kulutusorud Poola madalikel kui värskelt jäätumise alt vabanenud näidisala

Marek Majewski ja Renata Paluszkiewicz

Väikesed kuivad lühiorud esinevad parasvöötmes sageli ja on värskelt jäätumise alt vabanenud maastikele iseloomulikud. Käesolevas artiklis on uuritud Piaski Pomorskie ja Jasieńi ala orge Põhja-Poolas mitmete meetoditega ning on leitud, et orud kujunesid lineaarse kulutuse tulemusel Bøllingis ja Allerødis ning lihetena pärast jääaega külmadel perioodidel. Viimasest annavad märku mattunud erivanuselised orgaanikakihid.