SEDIMENTS OF HIGH-ENERGY MELTWATER FLOWS: EXAMPLES FROM CENTRAL POLAND, SAALIAN GLACIATION

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ABSTRACT
Outcrops of coarse grained fluvioglacial sediments, which originated in the conditions of high-energy flows, have been investigated within the extent of the Saalian II (Warta Stage) in Central Poland. They were accumulated during one of the recession phases of glaciation.
The article presents examples of erosion and sedimentation in two zones of meltwater activity, which differ as regards their relation to the ice margin. In the area of the Rzymsko esker (Turek Upland Plain), record of high-energy flows, which occurred in a glacial tunnel, often under hydrostatic pressure, has been documented. High water speed and flow, allowed for boulders of considerable size (0.5–1 m) to be transported, which resulted in great erosional force. High-energy flows in subglacial tunnels shaped vast erosional forms, cut not only in older sediments of the Pleistocene, but also in Cretaceous marls and limestones. Some forms were filled with esker sediments. Typical lithofacies of the Rzymsko esker include massive gravels with boulders, and trough and tabular cross-bedded gravels and sands. A characteristic feature of these sediments is the presence of openwork texture.
High-energy flows also occurred in the foreland of the Warta ice-sheet during glacial outburst floods. Sediments interpreted as an effect of such an event were analysed at the Siedlątków site (Łask Upland Plain). They form a vast stratum of massive boulders with sandy matrix.
Analyses of textural and lithological features of the sediments at the studied sites revealed their close similarity. Coarse grained glacifluvial sediments were characterised by high content of local rocks and significant rounding, which indicates considerable erosional force during flows. The conducted research may imply a far greater impact of high-energy flows on the shaping of landscape and sediment composition within the extent of the Warta ice-sheet than it has been acknowledged so far.

Keywords: glacifluvial sediments, esker, Warta Glaciation, Central Poland

INTRODUCTION
High-energy flows are a very characteristic phenomenon in the glacial environment, both in the areas of contemporary ice-sheets and glaciers and in the past geological epochs. They occur in two zones of meltwater activity (within the ice body and in the proglacial zone), and the sediments and forms originated as their result differ depending on the relation to their orientation to the front of the ice-sheet. Within the ice body, high-energy flows occur in subglacial, englacial and supraglacial channels, which are sometimes filled with the transported sediments. When large amounts of meltwater are released to the

foreland, glacial floods occur in which the flows may reach catastrophic discharges. The article presents examples of sediments which might represent the aforementioned zones in the area of Central Poland, within the extent of the Warta Glaciation. The research area includes fragments of the Turek Upland Plain near Rzymsko and Łask Upland Plain near Siedlątków (Fig. 1).

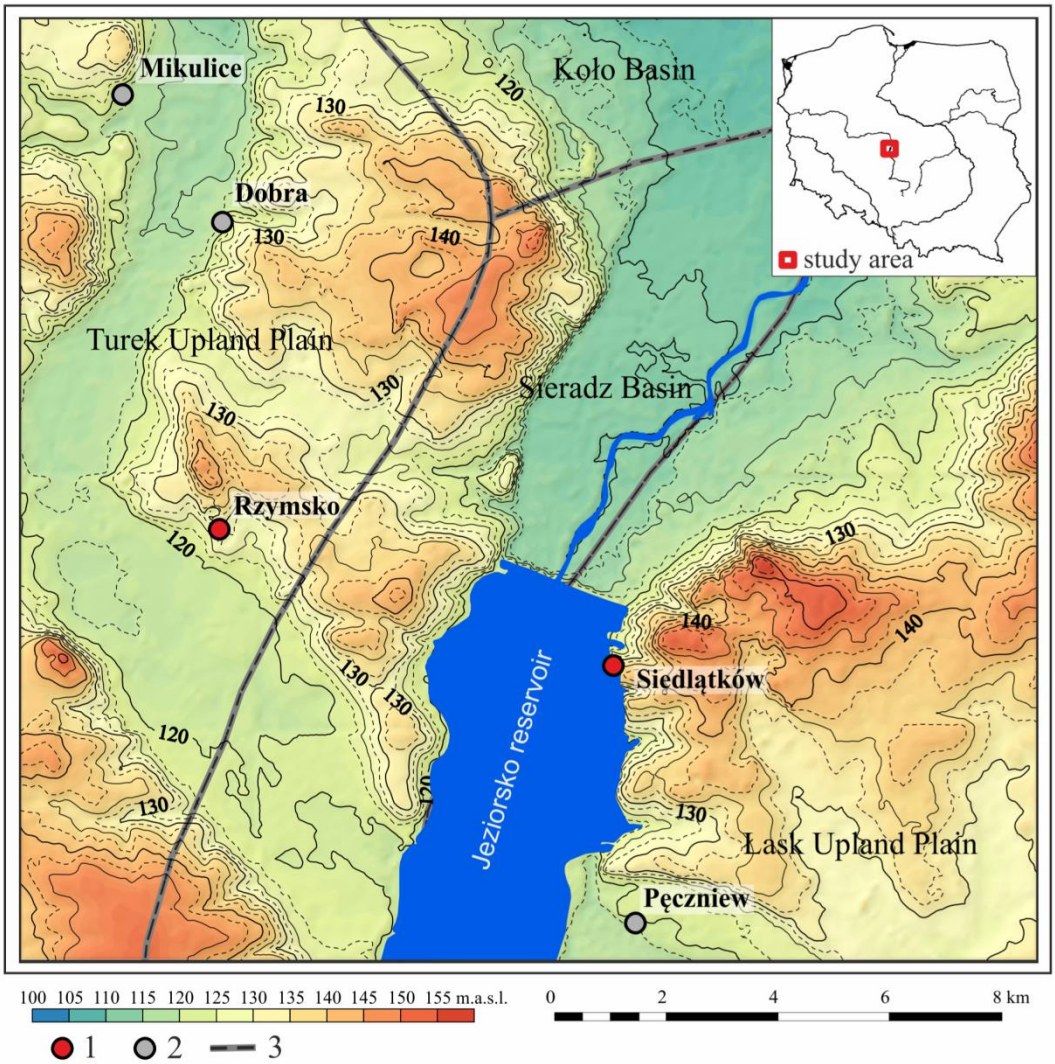

Figure 1. Location of the research sites in relation to the topographic conditions and physicogeographical division of Poland according to Kondracki 2001 [1]
1 – research sites, 2 – major towns and villages, 3 – physicogeographical mesoregions

Sediments of high-energy glacifluvial flows in the area of Poland have been studied mainly within the extent of the Weichselian Ice Sheet [2, 3, 4, 5] and they are considerably less recognised within the extent of the Saalian II Ice Sheet (Warta Stage). Although traces of glacial outburst floods in Wartanian sediments (compared to the jökulhlaup type of floods) were reported by Rdzany [6, 7], they have not been the subject of more in-depth research. For this reason, an attempt was made at indicating and analysing examples of high-energy flows of glacifluvial waters, which were accumulated both within the ice-body and in front of the ice sheet, during the Warta Glaciation.

METHODS

Research was conducted at two outcrops within the Rzymsko esker and the moraine plateau near Siedlątków. Geomorphological and sedimentological methods were applied. As part of sediment studies, lithofacies analysis was performed with the use of Miall's code [8] adapted to describing glacial outburst floods using the code modified by Maizels [9] (Tab. 1). The description includes three stratification thickness classes: small-scale units (< 6 cm), medium-scale units (6-30 cm) and large-scale units (> 30 cm).

Table 1. Nomenclature of the lithofacies used in the article [8, 9]

Code	Texture and structure	Code	Texture and structure
BGm	massive boulders and gravels	SGh	horizontally bedded sands and gravels
Gm	massive gravels	SGt	trough cross-bedded sands and gravels
Go	openwork gravels	SGp	planar cross-bedded sands and gravels
Gp	planar cross-bedded gravels	Sh	horizontally bedded sands
Gxt	large-scale trough cross-bedded gravels	Sp	plane cross-bedded sands
GSp	planar cross-bedded gravels and sands	Sm	massive sands
GSt	trough cross-bedded gravels and sands	Sr	ripple cross-laminated sands

In coarse-grained sediments, the maximum particle size (MPS) was measured, as the average length of the B-axis of ten largest clasts in a stratum. On the basis of clast and stratum orientation in the conditions of cross-bedding, the course of palaeocurrents was reconstructed. The content ratio of local material to Scandinavian material was determined in sediments of the gravelly and boulder fractions.

RZYMSKO ESKER - SEDIMENTS OF HIGH-ENERGY FLOWS IN SUBGLACIAL TUNNEL

The Rzymsko esker is located in the central and western part of the Turek Upland Plain. It is an elongated form of approximately 8 km of length, whose highest point is at 147 m a.s.l. The ridge is clearly noticeable in the landscape, and relative heights reach about 20 metres. The form starts to the south of Mikulice. Near Dobra, the esker is broken by the valley of the Teleszyna river, and it continues further to Rzymsko. The form is roughly meridional with a slight deviation from NNW to SSE. The outcrop where the research was performed is found in the southern part of the esker (Fig. 1). The esker is the filling of a tunnel valley [10], whose trace is the longitudinal depression along the form. The structure of the esker was analysed by Jaksa [11], who distinguished four sediment complexes: R1 – a 2-metre lithofacies complex consisting of Sp(Sh) lithofacies set and Sr lithofacies, R2 – a 3-metre stratum of massive gravels and cobbles (Gm), with sizes reaching 50 cm, R3 – a 1.8-metre complex consisting of Sh, GSp and SGt, R4 – a 5-metre complex built of repeating Gp lithofacies separated by erosional surfaces and fillings of shallow and vast erosional incisions – Gt. Due to considerable exploitation of the analysed outcrop, the described profile is not visible at present.

Sediments of high-energy flows occurred at various stages of forming of the esker, which is visible both in the profile of the outcrop and in results of previous research. The thickest and most coarse sediments of the type occur in the central part of the esker, forming its core. It is built mainly of lithofacies of trough and planar cross-bedded gravels and sands of medium and large scale (Fig. 2A)

Most gravels which form the esker are characterised by clast-supported texture. In part of fillings of the trough structures, openwork texture occurs, characterised by very good sorting and the lack of matrix (Fig. 2B). It is considered to be a diagnostic feature of the environment of high-energy flows, which must have been strong enough to carry away finer fractions. The texture is sometimes reported in eskers and sandurs, when at certain stages of their creation, the flow discharge reached catastrophic values [2, 4, 9, 12]. Openwork sediments show normal grading. In the upper part of the outcrop, a stratum of massive gravels and boulders with sandy matrix is distinguished (Fig. 2C). The size of largest boulders visible in the outcrop ranges from 0.5 to 1.0 m, and the MPS is 40 cm.

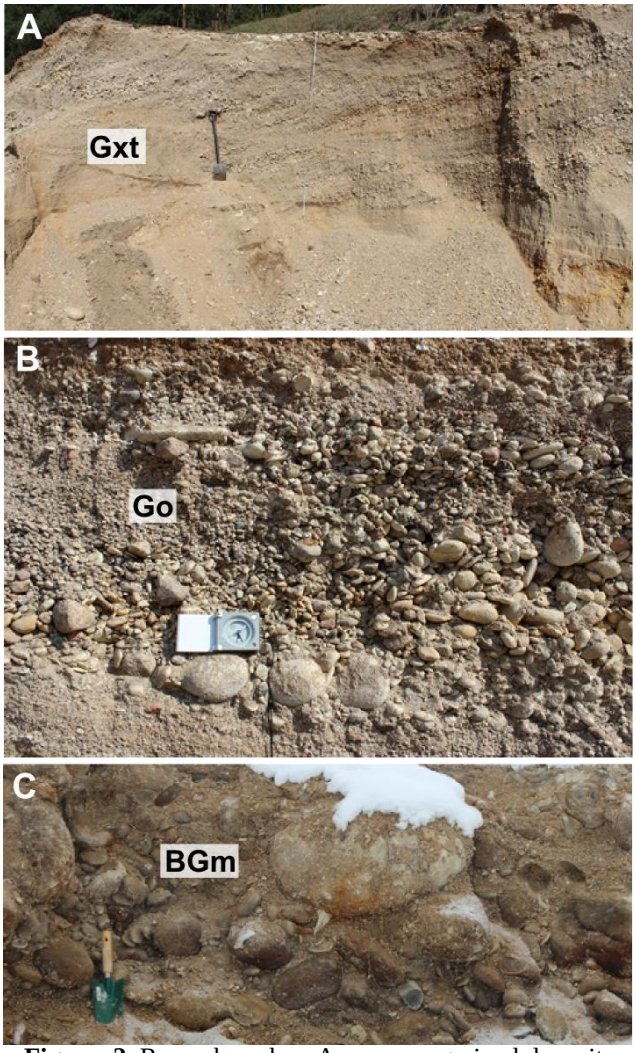

Figure. 2. Rzymsko esker. A – coarse-grained deposits with large-scale trough cross-stratification; 1,25 m spade for scale, B – Gravel with openwork texture, C – Matrix-supported boulders and gravels with massive structure in upper part of the outcrop; 0,3 m spade. Photo by M. Frydrych, 2015

A characteristic feature of the gravelly sediments which form the esker is the very high content of local rocks. In the gravelly layer with openwork texture, their content was established at 84%. A similar trend is observed for boulders. Both gravels and boulders are very well rounded, which was documented in earlier research [7, 11]. Orientation of long axes of the clasts indicates the dominating direction to be NNW to SSE – in accordance with the azimuth of the morphological axis of the esker.

SIEDLĄTKÓW SITE - SEDIMENTS OF GLACIAL OUTBURST FLOOD

The occurrence of coarse-grained glacifluvial sediments was observed in the exposed cliff of the Jeziorsko Reservoir, which forms the edge of the Łask Upland Plain. The analysed site is located in the northern part of the marginal zone of the reservoir, near Siedlątków

village. It is a zone of significant activity of the Warta ice-sheet, particularly during its recession [7].

The stratum of coarse-grained fluvioglacial sediments is visible in the outcrop along a section of several dozen metres. It consists of a lithofacies of massive boulders with gravelly and sandy matrix (BGm) (Fig. 3B) 0.8-m to 2-m thick, and an overlying stratum of massive gravels (Gm) (Fig. 3A). The floor and roof of the bouldery stratum is clearly distinguished (Fig. 4).

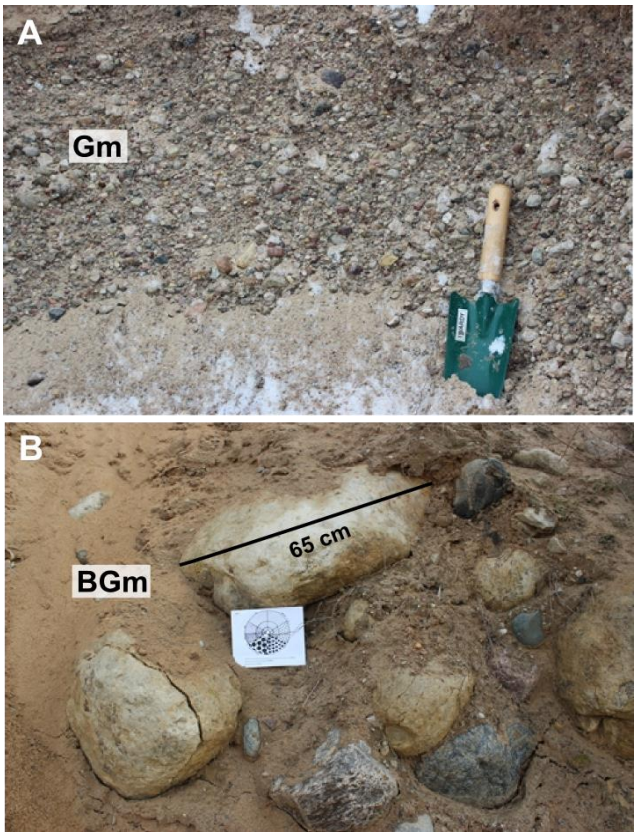

Figure 3. Jeziorsko site. A - massive gravels above BGm facies; 0,3 m spade, B - matrix-supported massive boulders and gravels.
Photo by M. Frydrych, 2015

The lower part of the outcrop is built of a complex of lithofacies: Sm, Sh and SGh. The course of the bouldery and gravelly stratum is not horizontal, but clearly undulated. It is especially noticeable in the northern part of the outcrop, where sediments form a vertical fold with a clayey core, which results in a strong bending of strata. The deformation might have occurred as a result of tangential pressures during oscillation of the front of the Warta ice-sheet. The upper part of the outcrop lacks clayey sediments, which does not, however, exclude such a genesis of the deformation. Ascending neotectonic movements and the presence of rafts of an outcrop of Mesozoic sediments – which is exposed on the abrasion platform of the cliff – in the underlying clay might also have influenced the origins of deformation.

The upper part of the outcrop consists of a lithofacies complex of horizontally bedded sands and gravels (Sh, SGh). The size of boulders in the BGm lithofacies sometimes exceeds 60 cm, and the MPS is 51 cm. The boulders are closely packed and characterised by good and very good rounding. High content of local rocks is noticeable, particularly in the sediments of the largest fraction.

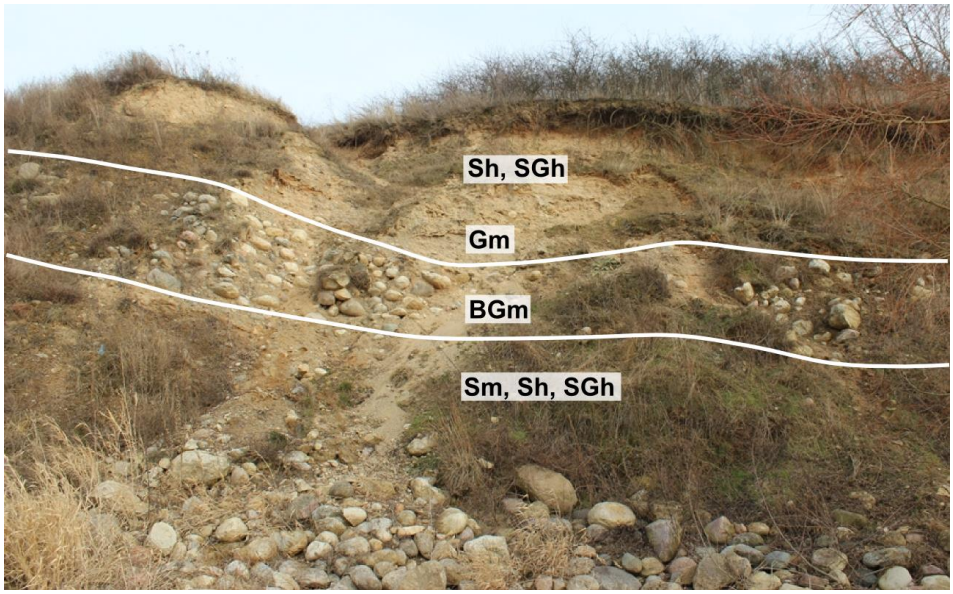

Figure 4. Siedlątków site; coarse-grained deposits accumulated during high-energy meltwater flow. Thickness of the BGm layer is about 2 m. Photo by M. Frydrych, 2015

DISCUSSION AND CONCLUSION

So far the area of Central Poland has been dominated by research into low-energy sediments, which occur much more commonly and are more easily accessible, e.g. in kames. Nevertheless, there are reasons to believe that high-energy flows played a much more significant role in depositing sediments and creating landforms than it is indicated by the current state of research. They are, however, more difficult to document as they are often the fills of deep tunnel valley, present only in buried form. The presented examples of sediments at the Rzymsko and Siedlątków sites represent sediments deposited in the conditions of high-energy flows. Analogical records of such processes with the participation of fluvioglacial waters are documented mostly in eskers and sandurs e.g.: [2, 3, 5, 9, 12], but the outcrops reveal a record of different environmental features of their accumulation. In the Rzymsko esker, accumulation occurred during subglacial flows. The presence of a large tunnel valley proves that it is an esker which was formed in an N-type channel. The transport took part mostly in hydraulic flow conditions in channels of considerable depth, as it is indicated by the dominance of Gt, GSt, SGt, Gp, SGp lithofacies of medium and large scale and normal grading. These flows were characterised by high energy, sufficient for transporting coarse gravels and forming the openwork texture. The flows might have occurred under full-pipe conditions. The sediments were deposited very rapidly. The profile of the esker reveals a cycle of subsequent floods, which are indicated by thickening of fractions, which is why it can certainly be stated that it was not formed as a result of a single large flow. Flow directions reconstructed on the basis of clast orientation (NNW-SSE) coincide with the orientation of the entire form. The presence of sediments of the BGm facies with sandy matrix is a record of periodical change of flow conditions from hydraulic flow to hyperconcentrated flow. Such flows might have occurred sporadically during significant increases of ice-sheet ablation or releases of sub-, estożen- and supraglacial reservoirs. Different sedimentation conditions were recorded at the Siedlątków site, where the BGm, Gm stratum is found between sediments (Sh, SGh) which rather indicate accumulation during sheetfloods. One may conclude that these sediments was acumulated in front of the ice-

sheet, in shallow and fast current. The BGm lithofacies might have been formed during a sudden and single flow of catastrophic dimensions during a glacial outburst flood. Gravelly sediments which occur higher, were accumulated during the reduction in current energy when the flood decreased.

Very close similarity of coarse-grained sediments at the analysed sites is also worth noticing. The dimensions of largest clasts and MPS are similar. Both in the esker sediments and in Siedlątków, the boulders are characterised by very good rounding and high content of local rocks. In particular the latter feature may confirm fluvioglacial genesis of the sediment in Siedlątków. Similarity of the sediments indicate a common source of material. The sites are not very far from each other, which is why it is probable that waters responsible for transport and accumulation of sediments in the esker and in Siedlątków came from a the same drainage system of the Warta ice-sheet. Near the analysed sites, the roof of Cretaceous carbonate rocks, which form the Pleistocene bedrock, is relatively shallow, which is why subglacial waters could easily erode them. Significant erosion of the bedrock, transport of bouldery material and very good rounding of clasts indicate high transport energy in subglacial tunnels, occurring probably often under hydrostatic pressure.

The research proved that catastrophic high-energy flows occurred during the recession phase of the Warta Glaciation in the area of the Turek and Łask Upland Plains. Coarse-grained deposits in the Rzymsko esker were deposited as a result of cyclical high-energy hydraulic and hyperconcentrated flows in a subglacial channel. The layer of boulders at the Siedlątków site may be the record of a single flow during a glacial outburst flood, which occurred in the marginal zone in front of the ice-sheet. Sediments which occur at both sites are very similar lithologically and texturally. The close similarity of sediments and short distance between the outcrops may indicate a connected drainage system, in which the analysed sediments were accumulated. Its functioning led to the creation of a complex of surface and buried landforms.

REFERENCES

[1] Kondracki J. Geografia regionalna Polski, Wydawnictwo Naukowe PWN SA. Warszawa, pp. 1-441, 2001

[2] Gruszka B. & Dobracka E. & Langer A. Poligeniczny oz w Kluczkowie koło Świdwina, NW Polska. In: Pisarska-Jamroży M. (red.) Osady glacigeniczne fazy pomorskiej od Uckermark po Równinę Białogardzką, Bogucki Wydawnictwo Naukowe, Poznań, pp. 85-96, 2011.

[3] Zieliński T. Sandry Polski północno-wschodniej: osady i warunki sedymentacji, Uniwersytet Śląski, Katowice, pp. 1-95, 1993.

[4] Pisarska-Jamroży M. Glacifluwialne facje strumieni przeciążonych zawiesiną na przykładzie plejstoceńskich osadów wschodniej Jutlandii i Pomorza Zachodniego, Przegląd Geologiczny, vol. 55-6, pp. 503-510, 2007.

[5] Pisarska-Jamroży M. & Zieliński T. Specific Erosional and Depositional Processes in a Pleistocene Subglacial Tunnel in the Wielkopolska Region, Poland, Geografiska Annaler: Series A, Physical Geography, vol. 94-3, pp. 429-443, 2012.

[6] Rdzany Z. Procesy ekstremalne w zapisie osadów i form warciańskich regionu łódzkiego, Landform Analysis, vol. 8, pp. 65-68, 2008.

[7] Rdzany Z. Rekonstrukcja przebiegu zlodowacenia warty w regionie łódzkim, Wydawnictwo UŁ, Łódź, pp. 1-310, 2009.

[8] Miall A. D. A review of the braided-river depositional environment. Earth-Science Reviews, vol. 13, pp. 1–62, 1977.

[9] Maizels J. Lithofacies variations within sandur deposits: the role of runoff regime, flow dynamics, and sediment supply characteristics, Sedimentary Geology, vol. 85, pp. 299–325, 1993

[10] Frydrych M. & Rdzany Z. Tunnel valleys of old glacial landsystems in Poland. Acta Geobalcanica. Volume 2, Issue 2, pp. 77–84, 2016.
DOI: http://dx.doi.org/10.18509/AGB.2016.08

[11] Jaksa A. Zmienność sedymentacji w ozie. Stanowisko Rzymsko. In: Gruszka B. (red.) Terenowe Warsztaty Sedymentologiczne, 08-12 września 2003, "Kemy i ozy - stary problem w nowym, sedymentologicznym ujęciu", Uniwersytet Śląski, Sosnowiec, pp. 40-45, 2003.

[12] Mokhtari Fard A. & Gruszka B. Subglacial conditions in a branching Saalian esker in north-central Poland, Sedimentary Geology, vol. 193, pp. 33-46, 2007.