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Original article

Enigmatic glacigenic ridges from the Odra Glaciation in the vicinity of Krzepice (Woźniki-Wieluń Upland, Poland)

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ABSTRACT

The central part of the Woźniki-Wieluń Upland is characterised by mature old glacial landforms associated with the Middle-Polish Glaciations. In some areas, however, more pronounced post-glacial landforms can be observed that were remodelled by later morphogenetic processes to a lesser extent. To the south-east of Krzepice, in the vicinity of Dolisko, there is an extensive depression in which twelve parallel ridges can be found. In terms of their morphology and location as well as due to their relationship to the surrounding landforms, the ridges examined resemble forms that would be referred to as drumlins, glaciotectonic forms or glacial curvilineations in late glacial areas. The material presented is the result of the initial research stage. The studies conducted in this stage involved primarily geomorphological mapping supplemented by an analysis of landforms on a shaded relief model and on an orthophotomap. At the current stage of studies on the glacigenic landforms in the vicinity of Dolisko, three scenarios concerning their origins have been put forward that need to be verified. The first scenario involves glaciotectonic origins, the second assumes that they were formed in the same manner as classic drumlins, fluted moraines or longitudinal squeeze ridges, and the third scenario assumes that they have the same origins as glacial curvilineations. The group of glacigenic ridges discussed is a glacial landform unique in southern Poland.

KEY WORDS: glaciotectonics, drumlins, glacial curvilineations, Odra Glaciation, Quaternary substrate relief

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1. Introduction

The contemporary relief of the Woźniki-Wieluń Upland features many glacigenic landforms from the Middle-Polish Glaciations (KLIMEK, 1966; GILEWSKA, 1972; KRZEMIŃSKI, 1974, 1999; SZUBERT, 2012). The configuration of the substratum and the nature of deglaciation played an important role in their distribution. It is assumed that areal deglaciation dominated in the area (KLIMEK, 1966; KRZEMIŃSKI, 1974, 1999). While the late glacial zone in Polish territory exhibits well preserved post-glacial landforms, in the old glacial zone they are much less pronounced. However, there are certain exceptions.

To the south-east of Krzepice, there is a pentagonal depression within a small escarpment. On its floor, twelve parallel ridges can be found, which are separated by longitudinal troughs. They run from the south-west to the north-east and then towards the north. The depression has been interpreted as a kettle hole with well-preserved ridges of unknown origin inside. No similar old glacial forms were previously reported in southern Poland or demarcated on geological and geomorphological maps.

The paper presents the results of the first stage of research aimed to determine the morphological and morphometric features of the landforms and also to identify the main morphogenetic factors.

At the current stage of studies on the glacigenic landforms from the vicinity of Dolisko, three scenarios concerning their origins have been put forward. The first one involves glaciotectonic origins, the second assumes that the ridges at Dolisko were formed in the same manner as

classic drumlins, fluted moraines or longitudinal squeezed ridges, and the third scenario assumes that they have the same origins as glacial curvilineations. Further research is planned to verify these three hypotheses of the rigdes origin.

2. Study area

Krzepice Depression belongs to the Woźniki-Wieluń Upland (KONDRACKI, 1994). It is a subsequent denudation basin that formed in clayey and silty-sandy Middle Jurassic deposits that are present just below or even outcrop on the surface. In some places they form fossil hummocks separated by subglacial channels and potholes eroded by glacial waters (SZUBERT, 2012). Middle Jurassic formations are overlaid with glacial deposits: glaciofluvial sand and gravel with silt intercalations as well as till that ranges from ca. 1.5 metres to 5 metres in thickness around Krzepice (HAISIG & WILANOWSKI, 1990).

Within the undulating floor of the Krzepice Depression, which BEDNAREK ET AL. (1992) refer to as a denudation plain, glacial landforms are present that are associated with the Odranian (Drenthe) Glaciation (KLIMEK, 1966; GILEWSKA, 1972). During the Wartanian (Warthe) Glaciation, the study area found itself on the forefield of the ice sheet, about 10 km south from its maximum extension.

Nowadays, these areas are used mainly for agricultural purposes. They are drained by a stream that flows into the Bieszcza River (Liswarta River tributary) in Krzepice.

The study area is located near the Dolisko hamlet, south-east of Krzepice (Figs. 1 and 2). The Jurrassic escarpment adjoins the depression with the glacigenic ridges, which are the subject of research.

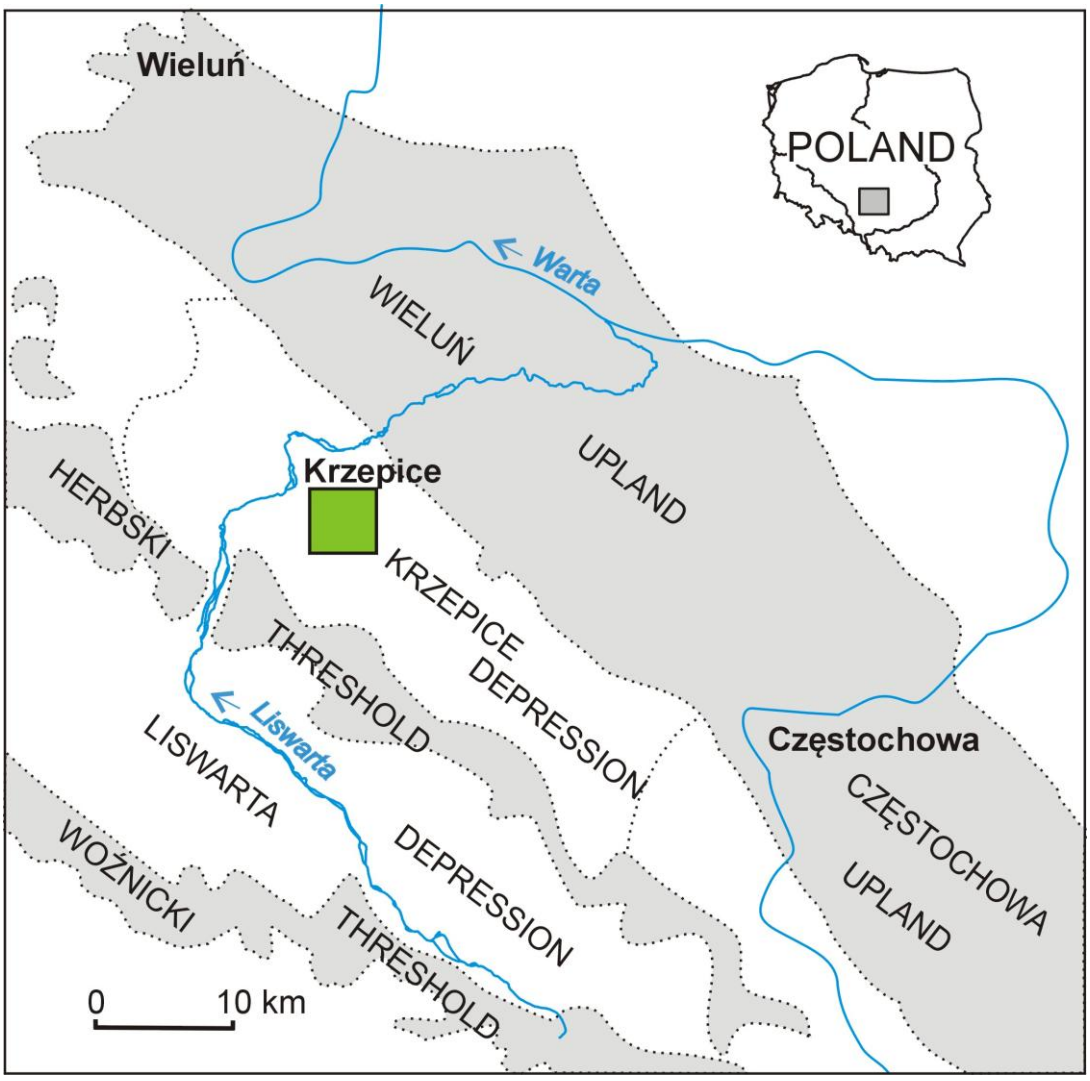

Fig. 1. Study area location marked with a green square with respect to the neighbouring physicogeographical units

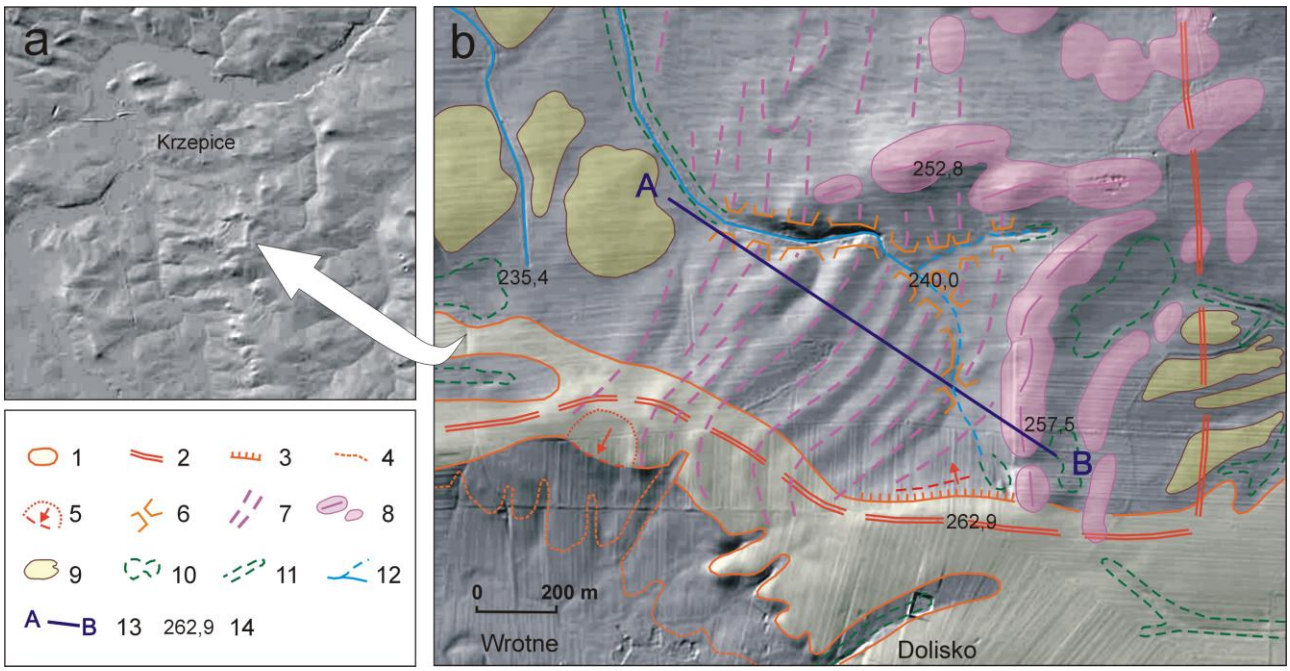

Fig. 2. Landforms in the vicinity of Krzepice
a – digital elevation model (data from the www.orsip.pl Silesian Province portal), b – geomorphological sketch of the study area in Dolisko: 1 – Middle Jurassic outcrops forming escarpment; 2 – ridge of escarpment; 3 – steep kettle slope; 4 – extent of slopes covered with diluvia; 5 – landslide; 6 – gorges; 7 – axes of glacigenic ridges; 8 – glacigenic deposits accumulated in ice crevasses and moraines; 9 – hummocks within ground moraine undulating plain; 10 – endorheic depressions; 11 – floors of erosion valleys; 12 – permanent and episodic watercourses; 13 – morphological profile line, 14 – altitude in m a.s.l.

3. Methods

During field work, geomorphological mapping was conducted, using the profile, skeleton and boundary tracing methods (KLIMASZEWSKI, 1978). Characteristics of the land surface in comparison to neighbouring areas was observed. A preliminary examination of the landforms deposits was conducted in erosional gullies, in dirt road cuts and in shallow (1,5 m) drillings from which samples were collected. The results of the field research were compared with the geological map 1:50,000, Krzepice (HAISIG & WILANOWSKI, 1985, 1990) and Kłobuck (BEDNAREK ET AL., 1987, 1992) sheets. Owing to the considerable size of the depression investigated, the shaded relief model and orthophotomaps were already used at the initial stage of the work (data from the www.orsip.pl Silesian Province portal).

The analysis of landform images made it possible to compare the landforms present in the vicinity of Krzepice with similar late glacial landscape features from northern Poland. The latter were described in numerous publications (e.g. JEWTUCHOWICZ, 1956; LAMPARSKI, 1972; CHUTKOWSKI & OLSZEWSKI, 2008; GŁĘBICKI & MARKS, 2009; LESEMANN ET AL., 2010, 2014; KARASIEWICZ ET AL., 2014). Together with data from a 1:10,000 scale topographic map, this analysis facilitated the description of the features found and morphometric calculations. Morphometric characteristics of the landforms were determined on the basis of field measurements.

4. Study results

The glacigenic ridges examined in the vicinity of Krzepice are situated within a depression that adjoins an elevation in the shape of an inverted L (Fig. 2b). This depression has the shape of a pentagon, it is over 20 metres deep and has an area of approximately 1.0 km^2. To the east, it is bordered by a large sandy ridge, oriented N-S, that is a remnant of a moraine or of material accumulated in an ice crevasse. To the north, there are a few elongated hills oriented W-E, composed of sand and gravel that HAISIG & WILANOWSKI (1990) classify as material accumulated in ice crevasses. To the west from the depression, there is the undulating till plain. Twelve parallel ridges are found in the central part of the depression. These first run from the south-west to the north-east and then adopt the north-south orientation. In the south, seven of them reach the latitudinal section of the elevation, which is built of clayey middle Jurassic formations (Fig. 2b). The ridges exhibit characteristic arched curves in that area. In the north, some of the ridges are hidden under the sandy and gravelly material accumulated in ice crevasses. Some ridges can also be discerned

further, around 2 km away, behind the elongated hills formed by the material accumulated in ice crevasses, but these are less pronounced. The ridges range from 333 to 952 m in length and from 38 to 124 m in width (Tab. 1). As a result of denudation processes, including agricultural activity, their height usually ranges from 0.5 to 1.2 m, but in the western part of the depression four of the ridges are higher than the others (Photo 1), and one of them is over 3.5 m high (Figs. 2 and 3). The elongation ratio (l/w) ranges from 4.2 to 18.8 (Tab. 1). According to the observations made so far, the ridges are built of the formations present in the substratum, i.e. of clay with crumbs of ferruginous sandstones and spherosiderites; in the eastern part, they are covered with a thin layer of moraine deposits in places. Alluvial humus and fine-grained mineral fraction (mud) are present in the troughs separating the ridges (Photo 2).

All the ridges are laterally dissected by stream valleys (Fig. 2b). In their upper reaches, the streams are episodic. The dissections are small overflow river gorges.

Table 1. Morphometric parameters of glacigenic ridges in Dolisko

Number of ridge (from the west; Fig.2b)	Dimensions of ridges (in m)			Elongation	Izometricity	Flattening
	lenght (l)	max width (w)	max height (h)	l / w	w / l	w / h
1	476	114	1.2	4.2	0.24	95.0
2	571	76	1.0	7.5	0.13	76.0
3	619	67	1.0	9.2	0.11	67.0
4	952	124	3.0	7.7	0.13	41.3
5	333	38	1.0	8.8	0.11	38.0
6	905	124	3.5	7.3	0.14	35.4
7	429	38	0.5	11.3	0.09	76.0
8	905	67	0.8	13.5	0.07	83.8
9	886	67	0.8	13.2	0.08	83.8
10	714	38	0.5	18.8	0.05	76.0
11	876	67	1.2	13.1	0.08	55.8
12	333	38	0.5	8.8	0.11	76.0

Photo 1. Glacigenic ridges in the depression near Dolisko, viewed from the west (*M. Fajer, February 2016*)

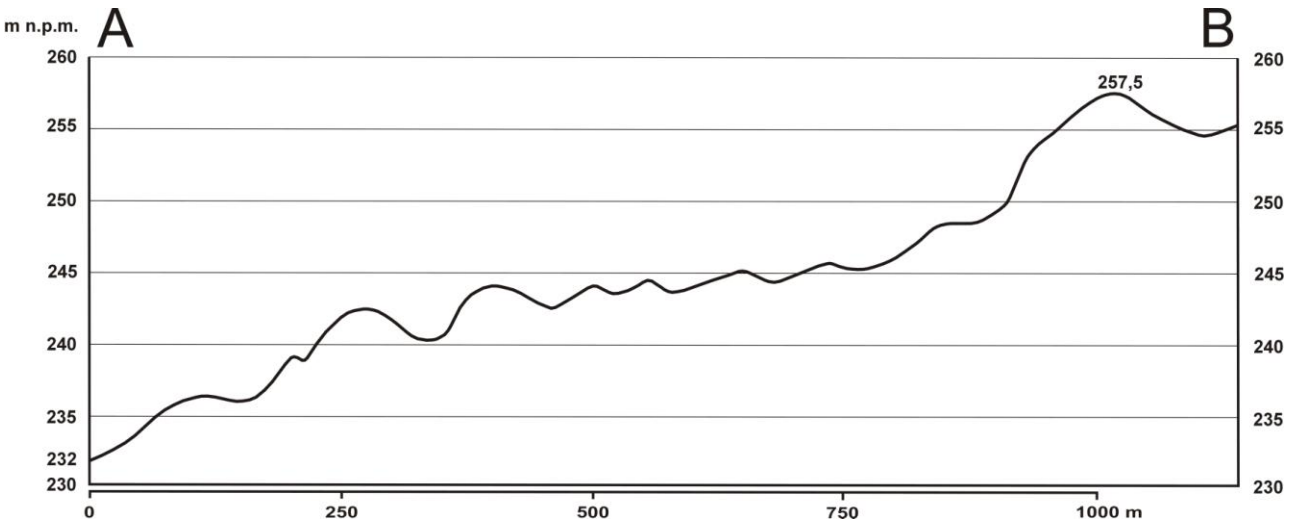

Fig. 3. Morphological profile of the depression with the glacigenic ridges in Dolisko

Photo 2. Troughs between glaciotectonic ridges filled with organic and mineral sediments, viewed from the east (*M. Fajer, February 2016*)

5. Discussion

The large depression in Dolisko with the 12 transverse ridges has a complex origin. The depression itself is probably a kettle hole. In terms of morphology and relationship to the surrounding landforms, a set of parallel ridges resemble forms that in late glacial areas are commonly referred to as drumlins (e.g. JEWTUCHOWICZ, 1956; LAMPARSKI, 1972; CHUTKOWSKI & OLSZEWSKI, 2008; GŁĘBICKI & MARKS, 2009), glacial curvilineations (LESEMANN ET AL., 2010, 2014), glaciotectonic forms (MOJSKI, 1979, KLATKOWA, 1993) or forms related to the disappearance of dead ice in the supraglacial system (JOHNSON & CLAYTON, 2003; MOJSKI, 2005; EVANS ET AL., 2014).

Similar forms from the Vistulian Glaciations are quite well pronounced on the shaded relief model (*Geoportal 2*) e.g. around Zbójno and Brodnica east of Toruń, in Pławęcino near Unieradz to the south of Kołobrzeg, east of Żydowo and east of Koszalin. Similarly pronounced glacial landforms are reported in central Poland, within the range of the Wartanian Glaciation. Citing the example of the Romanowskie Hills described by WIECZORKOWSKA (1975), MOJSKI (2005) emphasises the very limited extent to which the well-expresses glacial landforms from the Wartanian Glaciation have been transformed there. KRZEMIŃSKI (1974, 1997) points out similar features of Wartanian landforms in central Poland. In his opinion, these landforms have been only slightly transformed by the subsequent morphogenetic processes, and their

present apperance was close to original. In the case of Dolisko, the clearly visible depression and the set of parallel ridges are associated with a much older glaciation (the Odranian one), and therefore they are of particular interest. The preservation of the landforms presented in the paper was favoured by the direction of the latitudinal ice marginal valley that runs approximately 3 km north of Dolisko. When the Wartanian ice sheet reached its maximum extension, this ice marginal valley collected meltwater and drained it towards the west, and in the recession phase towards the east (SKOMPSKI, 1971; KOBOJEK & PRZYBYŁ, 1993; LEWANDOWSKI, 2015). Thus the role of the marginal valley was played by the Liswarta River valley, which protected the forms from being washed out or buried.

At the current stage of studies, it is difficult to unequivocally determine the origins of the landforms from Dolisko, and therefore three scenarios have been put forward.

1) The forms described may have been formed during the first phase of the Odranian ice-sheet transgression in the Woźniki-Wieluń upland as a result of the push of the Silesian glacial lobe that was advancing from the west (cf. RÓŻYCKI & LAMPARSKI, 1967; Fig. 4a). This lobe encountered the slope of a transverse elevation built of Middle Jurassic rocks, and the concavity within the elevation, which resembled an inverted L, trapped the ice inside for a period of time. During this movement the ice stream could have pushed the plastic clay of the substrate upwards so that folds parallel to the ice front formed, or it could have caused the clay to wrinkle. They could have been moved a certain distance forming a moraine consisting of material of local origin (cf. RÓŻYCKI & LAMPARSKI, 1967). The southern part of the Jurassic ridge (the base of the inverted L) delayed the movement of ice masses and of the piled-up clay ridges (Fig. 2b). This is an argument for the contribution of the glaciotectonic factor to the formation of the ridges. It appears that the preservation of the ridges was largely conditioned by the properties of the material of which they were built of (cohesion), and the long stagnation of the ice masses associated with the Silesian lobe. Those conserved the depression and the ridges present within it. From this point of view, the Dolisko ridges can be considered push moraines. Their origins can also be compared to small Rogen moraines at an early stage of their development (MENZIES & SHILTS, 2002; MARICH ET AL., 2005) or to washboard moraines (CLINE ET AL., 2015).

2) The orientation of the ridge landforms in Dolisko is consistent with the direction of movement of ice masses during the main phase of the Odra ice sheet advance (Fig. 4b), and thus is in line with the classical model of drumlin development. However, the small width and height of the ridges examined also suggests that they may be related to fluted moraines (MERTA, 1989). Drumlins sometimes evolve into fluted moraines (fluting assemblage) (MENZIES & SHILTS, 2002). Given their length of more than 300 m and elongation ratios ranging from 4.2 to 18.8, the landforms in question are similar to megaflutes. In view of the large proportion of material from the local substrate in these landforms, they could also be longitudinal squeeze moraines (GOUDIE, 2004; MIGOŃ, 2006). Drumlins, fluted moraines as well as squeeze moraines could have developed in Dolisko after the deposits and ice masses brought by the Silesian lobe had been exarated. The exaration of older sediments and the creation of ridges could have been caused by the thick ice masses that advanced from the north-northwest towards the Woźniki-Wieluń Upland during the maximum extension of the Odranian Glaciation (cf. RÓŻYCKI & LAMPARSKI, 1967; RÓŻYCKI, 1972; Fig. 4b).

3) An explanation for the formation of the Dolisko ridges that involves the spiral flows in basal ice model described by SCHOOF & CLARKE (2008), and the findings of the studies on glacial curvilineations on the Dobrzyń Plateau (LESEMANN ET AL., 2010, 2014) should be considered as well. Taking into account the long-term effect of denudation processes on the Dolisko landforms, which has reduced their height, it can be concluded that their morphology and morphometry are similar to many landforms on the Dobrzyń Plateau (CHUTKOWSKI & OLSZEWSKI, 2008).

The fact that the ridges in Dolisko were situated in the immediate vicinity of the escarpment that rises above, the nearby (running perpendicular to the ice-marginal valley) probably contributed to their preservation. SZUBERT (2012) ascribes a major role to subglacial channel drainage on the Woźniki-Wieluń Upland during the Odra Glaciation. During the deglaciation phase, the subglacial channels became routes for surface meltwater runoff and were gradually backfilled. At that time, the area occupied by the ridge landforms in Dolisko lay sufficiently high, so that it was not threatened by the erosion related to the abundance of glaciofluvial waters or by backfilling with glaciofluvial deposits. Additionally, the present depression in Dolisko could have been conserved for a long time by the slowly melting dead ice blocks.

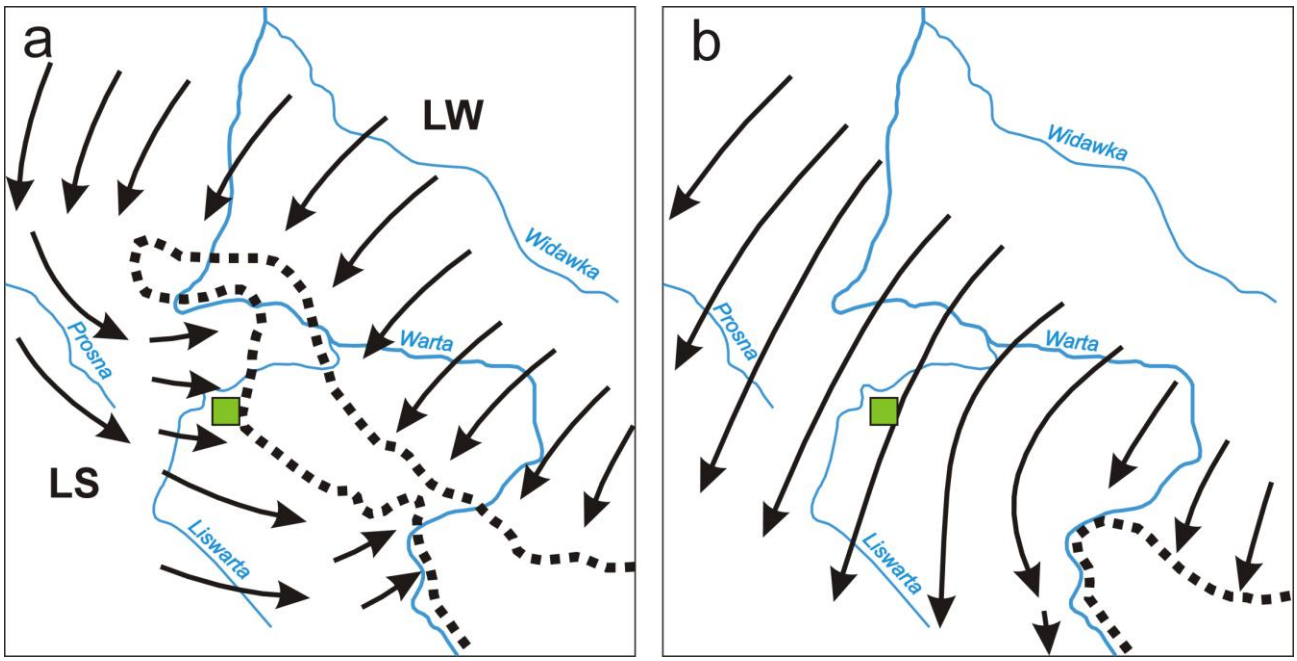

Fig. 4. Sketches depicting subsequent stages of the Odra ice sheet advancing into the Wieluń Upland (after Różycki & Lamparski, 1967, simplified)
a – initial stage, b – final stage. LS – Silesian lobe, LW – Widawka lobe. The dotted line indicates the location of the ice wall, arrows – the directions in which the ice sheet advances, and the green square – the study area

6. Summary

At the current stage of studies, it is difficult to unequivocally determine the origins of the landforms from Dolisko. In this paper, three working theories have been adopted that could explain the formation of the investigated longitudinal ridges. The first one points to glaciotectonic origins, the second assumes that they were formed in the same manner as classic drumlins, fluted moraines or squeezed ridges, and the third one assumes that they had the similar origins as glacial curvilineations. The issue should be settled by the planned studies of the ridges' internal structure, among others the texture, structure and deformation of deposits.

The group of ridges discussed in the paper is the only example of such glacial landforms having been preserved so well in southern Poland. Therefore it deserves legal protection as a geological site or a nature and landscape complex.

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