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The origin of drumlins at Zbójno, Central Poland

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Drumlins at Zbójno, Dobrzyń Lakeland, are located in a channel-like terminal basin, in the proximal part of the Chrostkowo end moraines. A fragment of the drumlin field was examined in detail. The drumlins are elongated ridges, parallel to one another and to the basin margins. Their orientation is parallel to perpendicular with regard to the presumed regional direction of the ice sheet advance. The drumlins' geological structure is tripartite, including a lower till, a glaciofluvial core and a covering upper till. Georadar examination indicated the presence and extension of glaciotectonic deformations of the lower till. It is squeezed up to 3 m above its primary setting and forms protodrumlins that have not been, however, the bed bumps that stimulated a lee-side deposition. Protodrumlins are usually absent along a drumlin axis, but they occur also in pairs. They could both initiate but also terminate drumlin development when thawing appeared in the subglacial zone and the ice body was disintegrated into dead-ice blocks. Glaciofluvial cores are less deformed than the lower till: their sediments are stratified, but commonly uplifted towards a protodrumlin.

Key words: drumlins, georadar, Pleistocene, Poland

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INTRODUCTION

Drumlins are commonly connected with an active ice body, and their inner deformations seem to result both from varying shearing stress and from lithologic inhomogeneity. Conservation of drumlins in a marginal zone of active ice is due to its resistance to shearing stress.

Preliminary classification of drumlins is always based on their morphologic description, what results in a varied inner structure, both in lithology and setting of sediments. A drumlin is usually found to present a tripartite structure:

– a glaciofluvial, lenticular core, resting on a bedrock (mostly lower till), covered with a thin upper till;

– glaciofluvial core that mantles emerging bedrock heights (protodrumlins) covered with the upper till;

– glaciofluvial core that mantles a protodrumlin, composed of the glaciodislocated lower till and covered with the upper till.

A protodrumlin is a component of a drumlin and is commonly defined as an emerging bedrock fragment resistant to glacial erosion. It is composed either of a lithic rock or of a glaciodislocated till. The prefix 'proto' means a primary element if its origin is concerned, and determines the derivation of a drumlin.

Drumlins are the outstanding landscape features characteristic of their specific shapes and collective occurrence. They are especially distinct in a fresh glacial landscape and are easily identified, both on topographic maps and in the field. Drumlins in the Polish territory have been studied for over 100 years (Keilhack, 1896; Werth, 1909; Ebers, 1926; Nechay, 1927; Pawłowski, 1927; Dylikowa, 1952; Jewtuchowicz, 1956; Wiśniewski, 1956; Niewiarowski, 1959; Roszkówna, 1961; Liberacki, 1961; Ber, 1968; Baranowski, 1969, 1977, 1979; Lamparski, 1972; Rudnicki, 1979). It resulted in a detailed description of drumlin fields, accompanied by their interpretation and original theories of their development (Lamparski, 1972). A renewed interest in Polish drumlins has begun lately (Wysota, 1991, 1992, 1994, 1995, 2004; Olszewski, 1994, 1995a, b, 1997; Piotrowski, Wysota, 2001).

The Zbójno drumlin field in the Dobrzyń Lakeland (Fig. 1) is the southernmost drumlin area in Poland. It occupies an area of about 130 km^2. Drumlins are located in a channel-like basin in the proximal part of the Chrostkowo end moraines. A fragment (30 km^2) of the central part of the

drumlin field was examined in detail. Drumlins at Zbójno are elongated ridges parallel to one another and to basin margins (Fig. 2). Their orientation varies greatly from parallel to perpendicular in regard to the accepted regional direction of the ice sheet advance.

METHODS

Morphometric measurements

Drumlins at Zbójno have quite composite shapes. Single hills have even up to a dozen local summits, therefore the short axis was measured every 50–100 m at narrowings and heights. The maximum, minimum and mean values of all the parameters for every feature were calculated, supplied also with a drumlin length / width ratio.

Georadar examination

It detected inner deformations in drumlins and enabled reconstruction of their development. Ninetteen sounding sections were examined (total length about 7000 m), including 4 sections along inter-drumlin depressions, 5 sections along hogbacks and 10 transversal sections. The sections formed a net whose junctions were precisely located with the use of GPS.

Drillings

Verification of archival boreholes, supplemented with examination of a few small outcrops, enabled to choose an area for georadar examination. The geologic structure of drumlins was documented with special drillings (12 boreholes, total depth over 100 m).

DRUMLIN MORPHOMETRY

Drumlins at Zbójno are not typical: they are extremely elongated (Fig. 2), generally up to 500 m (65%), but as much as 12% of them are over 2000 m (the longest drumlin is 4393 m long). Drumlin width is mostly 55–95 m. Therefore, finding a relation between the length and width of drumlins does not seem to be reasonable; on the other hand, there is a strict relation between their width and height (Fig. 3).

Slope inclination is uniform, except the drumlins that are transversally asymmetric. Thus, the width depends on primary height of the landforms. The described anomalies in drumlins are reflected by their mean ratio of length to maximum width, equal to 11.2. This value makes the morphometry of the drumlins to have no equivalents, either far-distant (Jauhianen, 1975; Piotrowski, 1987, 1989) or closer ones. In the neighbouring Chełmno and Dobrzyń Lakelands,

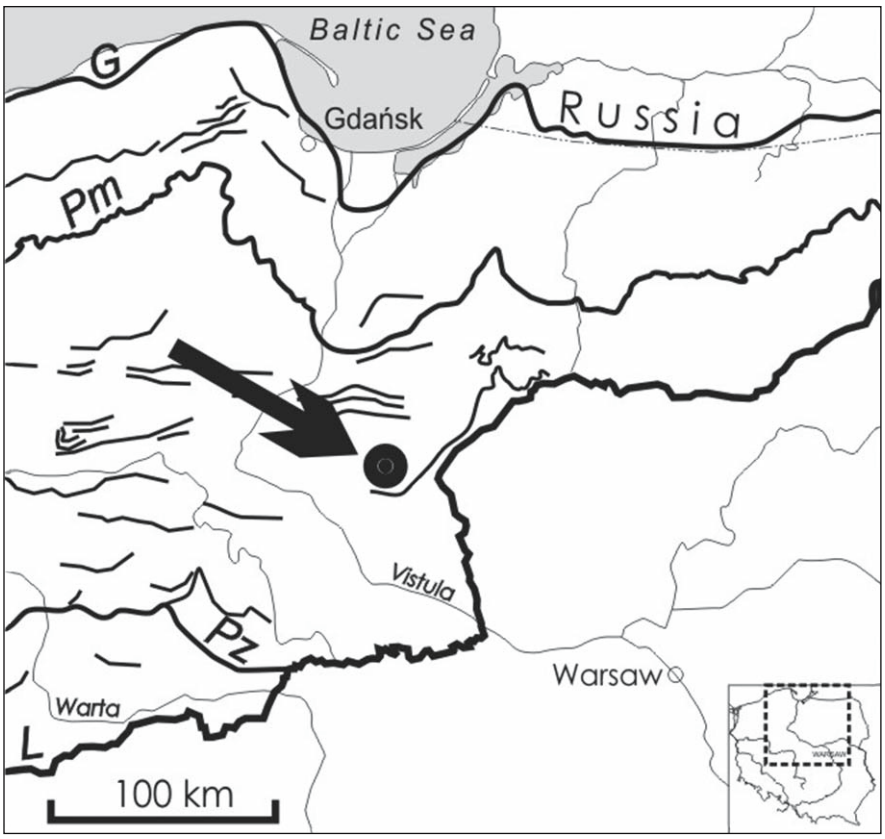

Fig. 1. Setting of the Zbójno drumlin field (arrow) against Vistulian (Weichselian) ice sheet limits: L – Leszno (Brandenburg) Phase, Pz – Poznań (Frankfurt) Phase, Pm – Pomeranian Phase, G – Gardno Phase
1 pav. Zbójno drumlinų lauko vieta (strėlė) paskutiniojo (Weichseliano) apledėjimo ribų atžvilgiu: L – Leszno (Brandenburgo) fazė, Pz – Poznanės (Frankfurto) fazė, Pm – Pomeranijos fazė, G – Gardno fazė

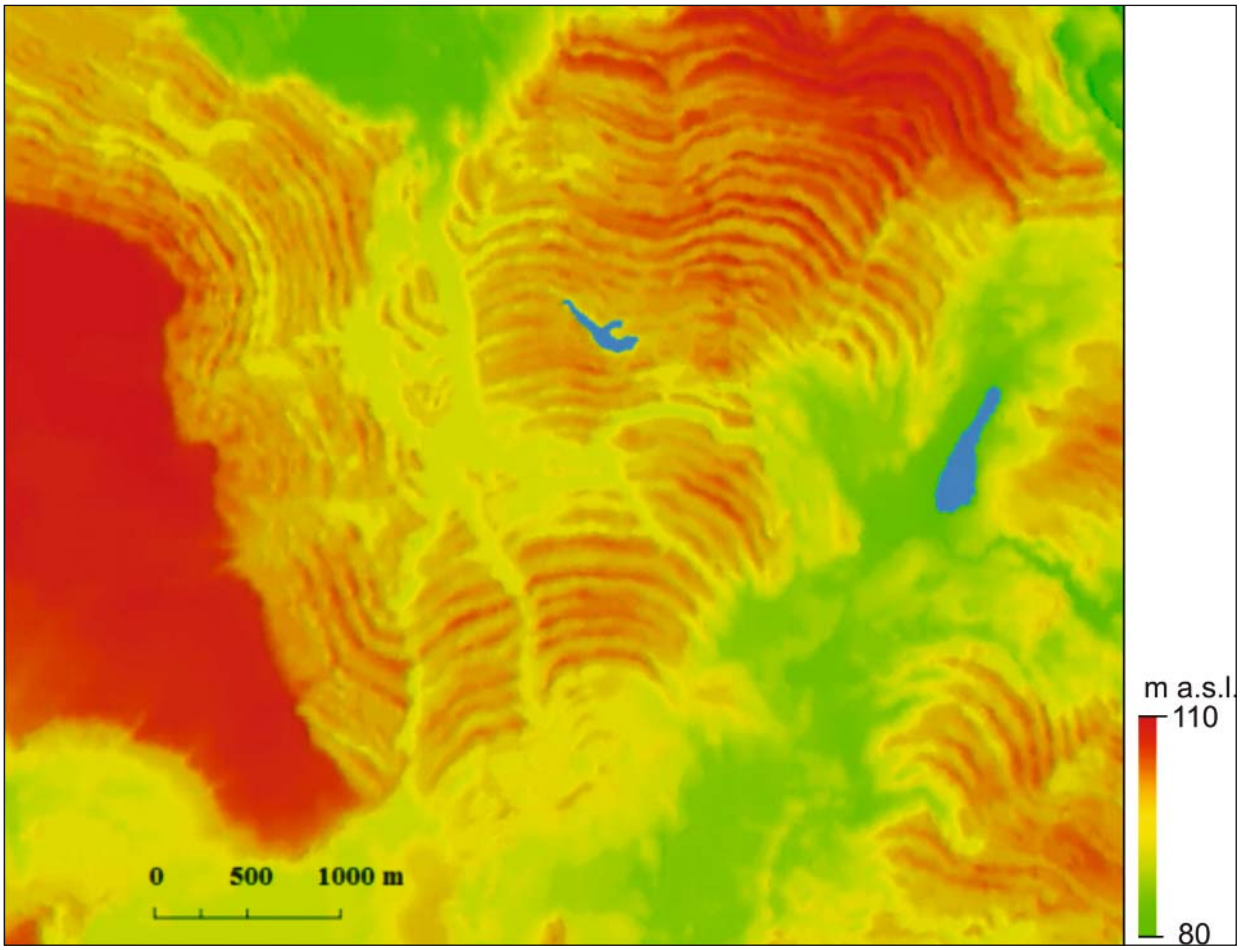

Fig. 2. Relief of the Zbójno drumlin field
2 pav. Zbójno drumlinų lauko reljefas

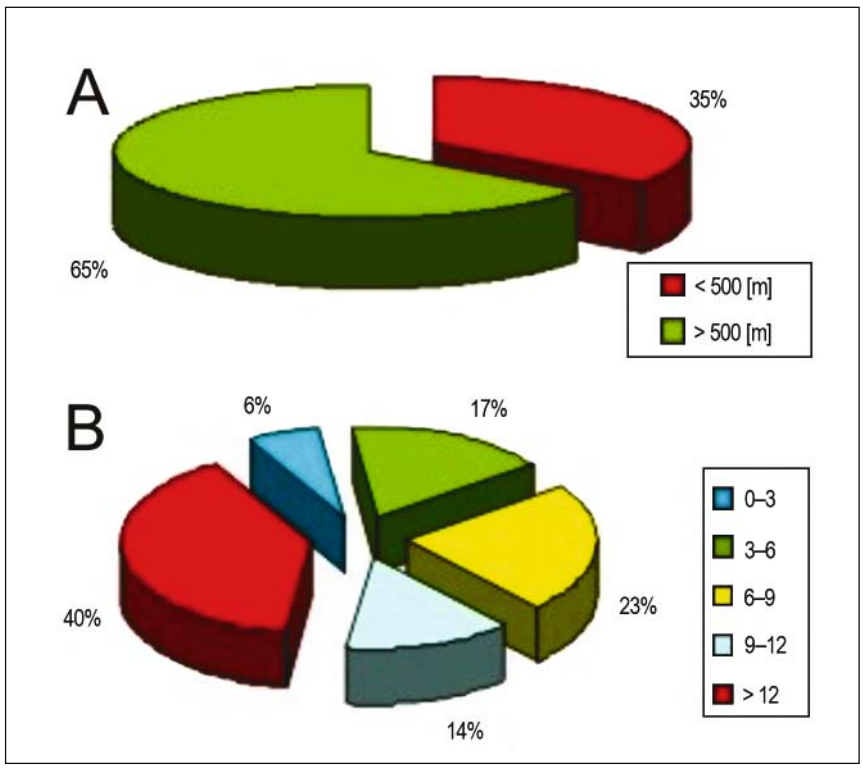

Fig. 3. Morphometry of drumlins at Zbójno: *A* – drumlin length, *B* – drumlin height
3 pav. Zbójno drumlinų morfometrija: *A* – ilgis, *B* – aukštis

the length / width ratio was estimated at 2.3 to 3.0, width being equal to 41.6 m (Wysota, 1993). The width at the Zbójno field is equal to 67.0 m.

INTERPRETATION OF GEORADAR EXAMINATION RESULTS

Detecting the depth of the lower till was of primary importance. The soundings were arranged in a regular network, but the dense vegetation cover as well as numerous water bodies and marshes disrupted it locally, especially in inter-drumlin depressions. The available sounding depth seems sufficient to find deformations in drumlins whose height is locally greater than the sounding depth equal to 6 m. All georadar sections indicate presence of inner structures parallel to the land surface (Fig. 4). The results of soundings, supported by results of drillings, can be classified into three groups.

The first group comprises sections along drumlin ridges running across their 1–3 local heights. Within the lower till, there are deformations with a maximum amplitude of about 2 m. No longitudinal asymmetry of protodrumlins was noted; therefore, there were no indications of ice sheet advance direction or of glacial erosion in the proximal part.

The second group is composed of soundings along the inter-drumlin depressions. However, water reservoirs either disrupted or deflected the expected sections. There are regular reflections to a depth of 2.0–2.5 m, but 3–5 of them record presumably the successive deposition phases within the inter-drumlin depressions. Therefore, the primary depth of these depressions could be even as much as 2.5 m. Beneath these depressions, there are two weaker reflections at a depth of 4.5 and 5.5 m, but they occur already within the lower till.

The third group of soundings comprises the sections that are roughly parallel to one another, at distances of about 50–75 m each. Their inner structure is similar, with diapirs of the lower till, a bipartite glaciofluvial core and non-central location of the second buried height.

Electromagnetic waves penetrate into soil perpendicularly to the surface, and it is especially misleading for the interpretation of such minute features as the Zbójno drumlins.

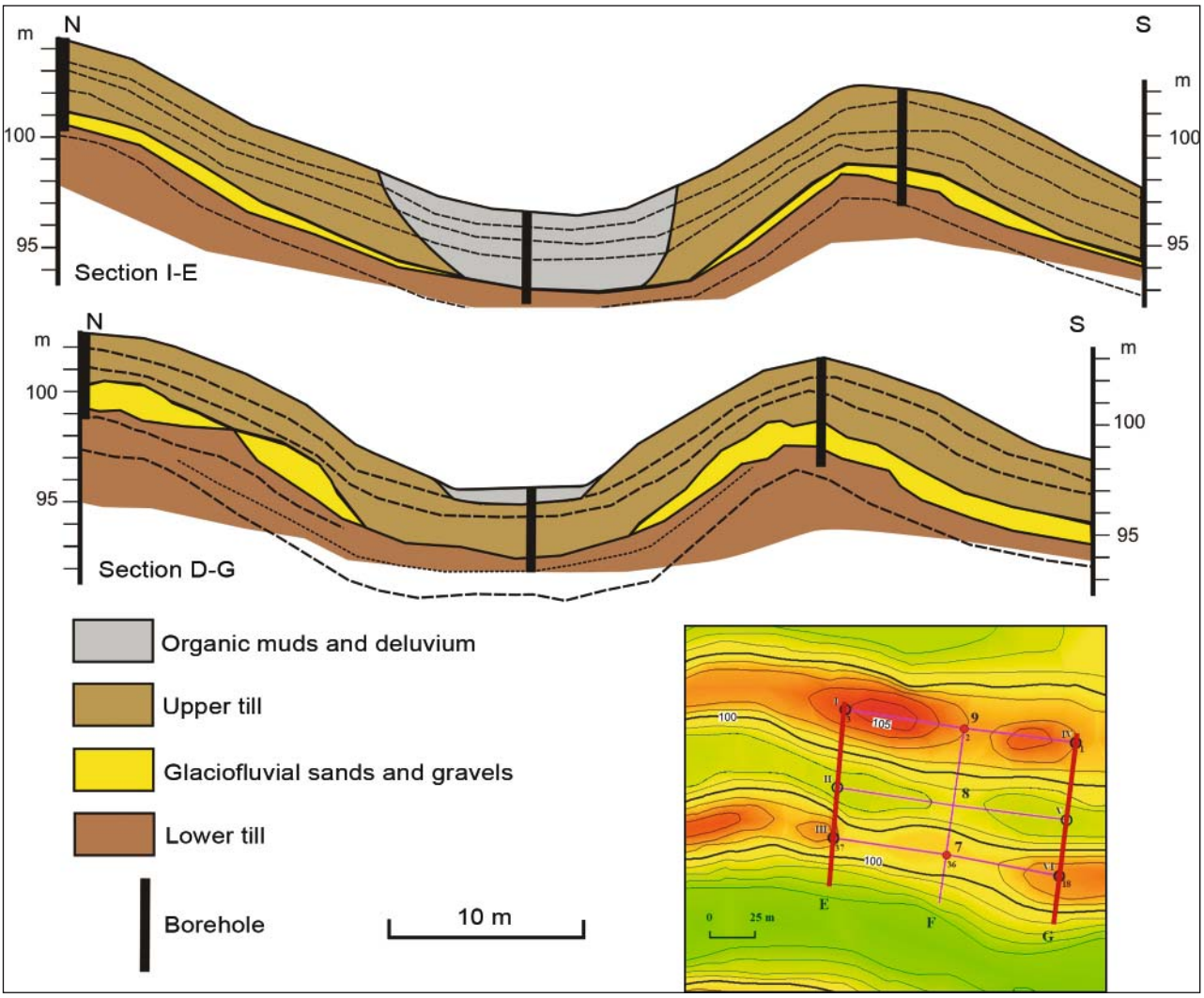

Fig. 4. Interpretation of georadar sections (examples)
4 pav. Georadaru gautų duomenų interpretacija

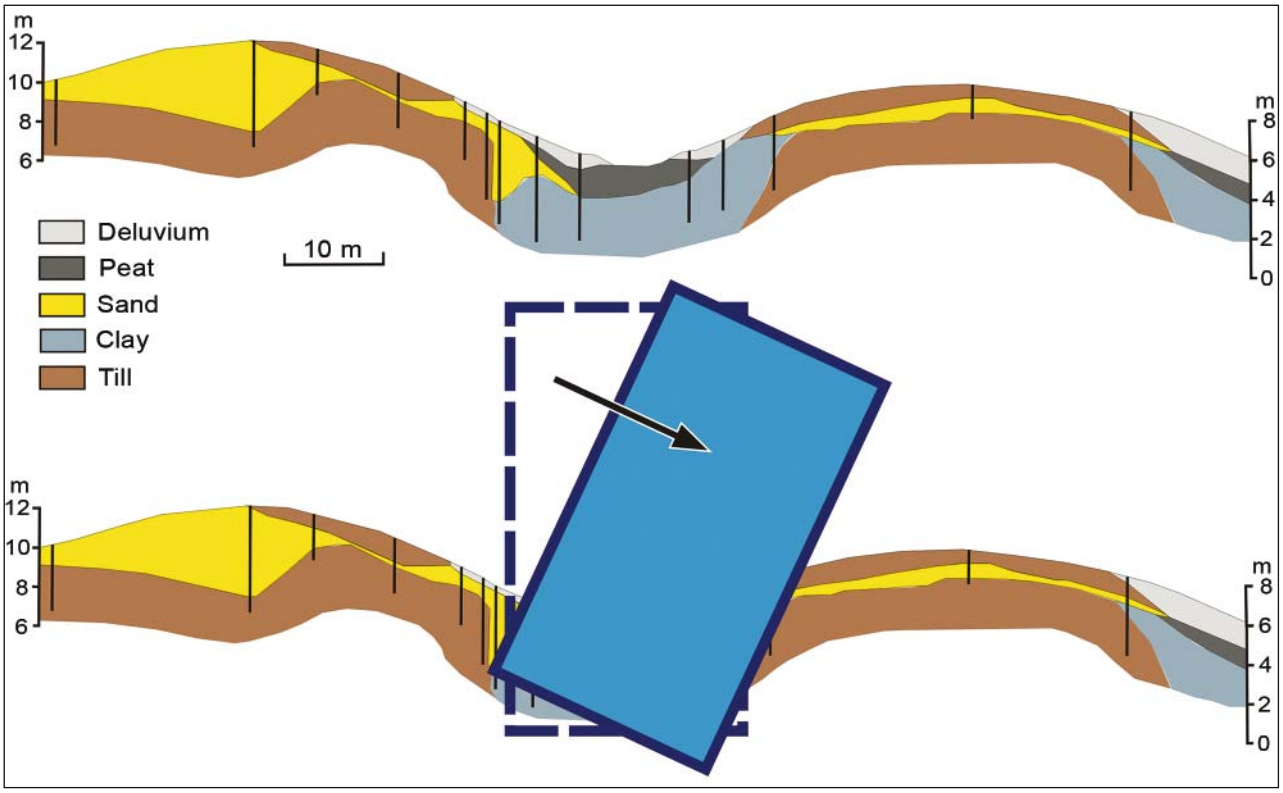

Fig. 5. Transversal section of a drumlin after Jewtuchowicz (1956), modified; the lower section presents a hypothetical deforming dead ice block
5 pav. Drumlinų skersiniai pjūviai (pagal Jewtuchowicz, 1956); modifikuoti, apatinė dalis su hipotetiniu deformuojančiu negyvo ledo bloku

Not all reflections are supported by the geological structure examined in boreholes; principally, some of them double the land surface.

GEOLOGICAL STRUCTURE OF DRUMLINS

The structure of drumlins at Zbójno implies they were modelled in a soft bedrock susceptible to plastic deformations. The drumlins are composed of a lower till, a glaciofluvial core and a covering upper till (Fig. 5). Both tills vary in their grain size composition: the lower contains generally less coarse grains i.e. 4.6% of sand and 5.4% of gravel and boulders (Jewtuchowicz, 1956).

Lower till

The lower till is most intensively deformed, squeezed even 3 m above its primary position. Its top is generally parallel to land surface, rising up to 2–3 m in the axial part and dipping steeply in depressions between the hills, even to a depth of 8.5 m beneath a drumlin base. The amplitude of deformations varies from about 4.5 m to over 12 m. The lower till is sandy brown and massive. It contains occasional sandy and sandy-gravel lenses and streaks, each up to 10 cm thick, accompanied by scarce boulders up to several dozen centimetres in diameter.

Squeezed diapirs of the lower till could act as protodrumlins; however, they were not bed bumps that stimulated a lee-side deposition. Linearly orientated protodrumlins are accompanied neither by glacial erosion nor deposition; therefore, their modelling under an active ice body seems hardly possible. Protodrumlins do not occur usually at drumlin axes and there are occasionally more than one of them in the transversal section.

Glaciofluvial core

Glaciofluvial cores of drumlins are considerably less deformed. The sediments are composed of stratified sands and sands with gravels. The structure is predominated by flat and cross-stratification (Jewtuchowicz, 1956), with varied azimuths and inclination (to 5–46°). The material is not uniformly sorted: it is mainly gravel, seldom sand and contains also scarce pebbles. Sediments of the glaciofluvial core are commonly deformed close to a protodrumlin. It means that a steering deforming force acted mostly beneath the glaciofluvial sediments and was almost entirely absorbed by the lower till.

Upper till

It is from a dozen centimetres at drumlin tops to over 3 m thick at the flanks. The till is distinctly stratified, with a characteristic leaf-like structure and detachment planes parallel to the top of glaciofluvial deposits. The inclination of these planes is similar to the drumlin slopes and changes from almost horizontal at the top to almost vertical ones at flanks. The plane strike is parallel to the longer axis of the drumlins.

Inter-drumlin depressions are occupied by small water reservoirs, occasionally elongated and commonly parallel to drumlin longer axes. Depression systems resemble a channel net, indicating a significant role of meltwaters in landscape development (Lamparski, 1972). The lower till in the inter-drumlin depressions is covered by clayey and locally sandy grey deposits, in places rather thick. They are overlain by a thin (1–2 m) peat or sandy-clayey deluvium. At the saddles that separate local drumlin heights, the depressions are infilled only by a thin deluvium resting straight on the lower till.

A CONCEPTUAL MODEL OF DRUMLIN FORMATION

Morphometric measurements indicate that only about 6% of drumlins at Zbójno have their length / width ratio equal to 3 and that in as much as 40% of them it is four times larger (Fig. 3). It is, however, striking that drumlins can be easily correlated almost across the whole study area (Fig. 2). Thus, their creative factor acted on a macro-scale and could be later replaced by erosion, transversal to elongation of the drumlins.

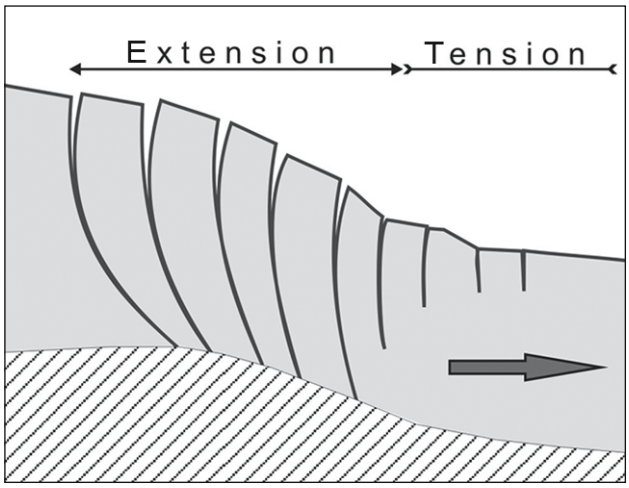

Fig. 6. Crevasses in the ice sheet body, developed by stress over an inclined bedrock. Gray arrow indicates the direction of ice sheet movement; after Röthlisberger and Lang (1987), modified

6 pav. Plyšiai ledyno kūne, atsiradę dėl įtampos slenkant pakilusiu uolienų pagrindu; pilka strėlė rodo ledyno judėjimo kryptį (pagal Röthlisberger ir Lang, 1987)

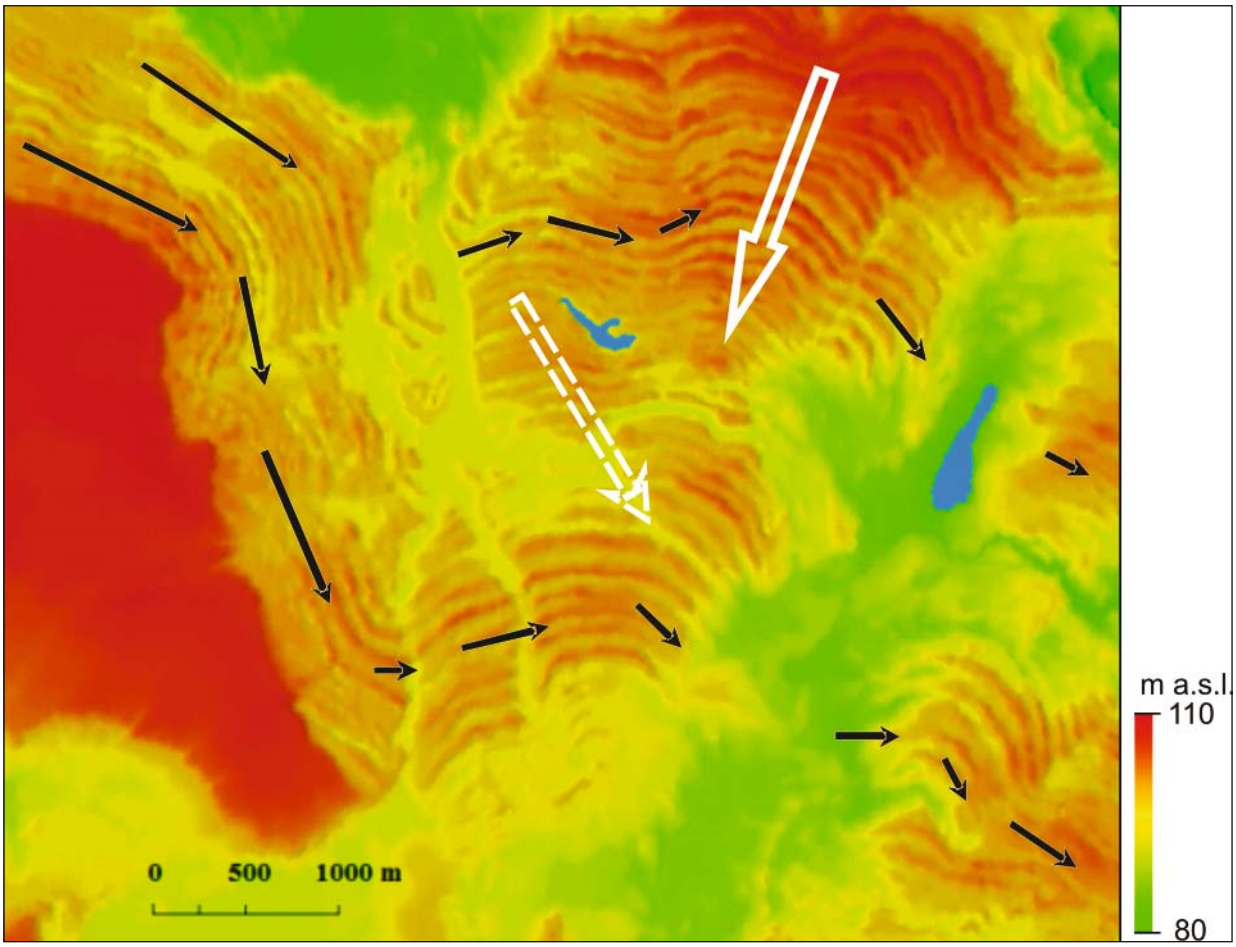

Fig. 7. Ice sheet movement according to the authors (white arrow) against regional ice sheet movement (white dashed arrow) after Lamparski (1972) and orientation of drumlins (black arrows)

7 pav. Ledyno judėjimas pagal autorius (balta strėlė) lyginant su regionine ledyno judėjimo kryptimi balta punktyrinė strėlė (pagal Lamparski, 1972) ir drumlinų orientacija (juodos strėlės)

The Zbójno drumlins contain protodrumlins inside, composed of the lower till. Their setting is commonly non-axial and considerably varies, and even within a single feature there is more than a single diapir. However, it has not formed an obstacle for a lee-side glaciofluvial deposition but was rather orm-in-form, running locally along the whole drumlin hill.

Therefore, in the case of favourable factors of the ground and a relatively high extra loading, an expulsion of sediments from under the hypothetical dead ice blocks could be possible (Fig. 5). The varied inclination of the bedrock made the semiplastic body of the glacier be subjected in turn to tension and to extension (Fig. 6). The newly created crevasses were kept preserved in the ice body and became open as deep and narrow cracks during intensive melting. If the present drumlins are to be considered as an image of the cracks that were filled, according to supraglacial theory, by glaciofluvial deposits, then the distribution of dead ice blocks in the Zbójno drumlin field can be reconstructed.

A hypothetical ice block between the neighbouring drumlins (Fig. 7) could deform the lower till: the forces acted non-axially and the deforming element was tilted. In such a case, the resulting leverage intensified the deformations and more than a single protodrumlin could be formed, commonly in a non-axial setting.

The crevasses in the ice body developed parallel to morphologic escarps. If an ice sheet enters a basin-like depression, the crevasses in its surface run semi-circular, resembling these escarps. The extension on the convex slopes is active on the ice surface, whereas on the concave slopes a tension is possible at the contact of the ice sole and the bedrock. It does seem obvious that the non-typical setting of drumlins at Zbójno, the common change of their orientation and a semi-circular system in the centre of the study area, all resemble a system of crevasses in an ice sheet that entered a vast depression.

CONCLUSIONS

– Drumlins at Zbójno are long, even several kilometres long ridges composed of tills and glaciofluvial deposits. The drumlins run parallel to one another and have characteristic sinusoidal transversal profiles.

– Georadar investigations have proven presence of glaciotectonic deformations within drumlins. The lower till is deformed and has been squeezed from the bottom of the drumlin up to 3 m in its inner part. Such squeezing, locally in non-axially arranged diapirs, formed the protodrumlins.

– A protodrumlin could be either a primary element with an erosive contact, but also it could be formed much later when the modelling processes of a drumlin have been already considerably far-advanced.

– Deformations of glaciofluvial deposits are particularly intensive at the contact with the diapirs. The bedding in the glaciofluvial core is more inclined in the drumlins in which the lower till penetrated more upwards in their inner part.

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References

1. Baranowski S. 1969. Some remarks on the origin of drumlins. *Geographia Polonica* 17: 195–208.
2. Baranowski S. 1977. Regularity of drumlins distribution and the origin of their formation. *Studia Geologica Polonica* 52: 53–68.
3. Baranowski S. 1979. The origin of drumlins as an ice-rock interface problem. *Journal of Glaciology* 23: 435–436.
4. Ber A. 1968. Stratygrafia czwartorzędu okolic Dobrzynia nad Wisłą. *Acta Geologica Polonica* 18(3): 663–676.
5. Dylikowa A. 1952. O metodzie badań strukturalnych w morfologii glacjalnej. *Acta Geographica Universitatis Lodziensis* 3.
6. Ebers E. 1926. Die bisherigen Ergebnisse der Drumlinforschung. *Neues Jahrbuch für Mineralogie* 53.
7. Jauhiainen E. 1975. Morphometric analysis of drumlin fields in northern Central Europe. *Boreas* 4: 219–230.
8. Jewtuchowicz S. 1956. Struktura drumlinów w okolicach Zbójna. *Acta Geographica Universitatis Lodziensis* 7: 1–74.
9. Keilhack K. 1896. Die Drumlinlandschaft in Norddeutschland. *Jahrbuch der Königlichen Preussisch Geologisches Landesamt und Bergakademie* 17: 163–188.
10. Lamparski Z. 1972. Geneza form drumlinowych okolic Zbójna (Pojezierze Dobrzyńskie). *Acta Geologica Polonica* 22(1): 139–158.
11. Liberacki M. 1961. Drumlins near Zbójno. Guide-Book of Excursion. Part I: North Poland. *6th INQUA Congress, Poland*. 115–117.
12. Nechay W. 1927. Utwory lodowcowe Ziemi Dobrzyńskiej. *Sprawozdania Państwowego Instytutu Geologicznego* 4: 1–2.
13. Niewiarowski W. 1959. Formy polodowcowe i typy deglacjacji na Wysoczyźnie Chełmińskiej. *Studia Societatis Scientiarum Torunensis* C 4(1).
14. Olszewski A. 1994. Zbójeński obszar drumlinowy (część północno-zachodnia). In: E. Wiśniewski (ed.). *Formy, osady i procesy subglacjalne. Symposium, Toruń–Górzno, 28–29 September 1994*. Toruń: Instytut Geografii Uniwersytetu Mikołaja Kopernika. 44–53.
15. Olszewski A. 1995a. Zbójecko I – Zbójno drumlin field, morphology and structure of drumlins. In: W. Schirmer (ed.). *Quaternary field trips in Central Europe. Regional field trips 1: 210*. München.
16. Olszewski A. 1995b. Wojnowo – kames in the Zbójno drumlin field. In: W. Schirmer (ed.). *Quaternary field trips in Central Europe. Regional field trips 1: 211*. München.

17. Olszewski A. 1997. Drumlins of the northwestern Dobrzyń Moraine Plateau, location, structure and morphogenesis. *Quaternary Studies in Poland* 14: 71–83.
18. Pawłowski S. 1927. Krajobraz drumlinowy okolic Kobrynia. *Przegląd Geograficzny* 7.
19. Piotrowski J. A., Smalley I. J. 1987. The Woodstock drumlin field, southern Ontario, Kanada. In: J. Menzies, J. Rose (eds.). *Drumlin Symposium.* Rotterdam: Balkema. 309–321.
20. Piotrowski J. A. 1989. Relationship between drumlin length and width as a manifestation of the subglacial processes. *Zeitschrift für Geomorphologie Neue Folge* 33: 429–441.
21. Piotrowski J. A., Wysota W. (eds). 2001. Drumlins: the unsolved problem. Field excursion guide book. *6th International Drumlin Symposium. Toruń, June 17–23, 2001*. Toruń: Nicholas Copernicus University. 100 p.
22. Roszkówna L. 1961. Drumlins near Gniew (Morzeszczyn). Guide-Book of Excursion. Part I: North Poland. *6th INQUA Congress, Poland*. 84–86.
23. Röthlisberger H., Lang H. 1987. Glacial Hydrology. In: A. M. Gurnell, M. J. Clark (eds.). *Glacio-fluvial Sediment Transfer – an Alpine Perspective*. London: Wiley & Sons, Ltd. 207–284.
24. Rudnicki J. 1979. Charakterystyka deformacji osadów drumlinowych okolic Zbójna. *Biuletyn Geologiczny Uniwersytetu Warszawskiego* 23: 143–153.
25. Werth E. 1909. Eine Drumlinlandschaft und Rinnenseen südlich von Posen. *Zeitschrift der Deutschen Geologischen Gesellschaft* 61.
26. Wiśniewski E. 1956. Formy drumlinowe okolic Gniewu. *Przegląd Geograficzny* 37: 171–182.
27. Wysota W. 1991. Morfologia, budowa wewnętrzna, struktura i geneza drumlinów w środkowo-wschodniej części Pojezierza Chełmińsko-Dobrzyńskiego. *I Zjazd Geomorfologów Polskich, Poznań, 24–25 September 1991*. Poznań: Instytut Badań Czwartorzędu Uniwersytetu Adama Mickiewicza. 78–79.
28. Wysota W. 1992. *Morfogeneza środkowo-wschodniej części Pojezierza Chełmińsko-Dobrzyńskiego w świetle badań osadów i form zlodowacenia vistuliańskiego*. Toruń: Uniwersytet Mikołaja Kopernika.
29. Wysota W. 1993. Geneza drumlinów w środkowo-wschodniej części Pojezierza Chełmińsko – Dobrzyńskiego. *Przegląd Geologiczny* 91: 335–361.
30. Wysota W. 1994. Górznieński obszar Drumlinowy. In: E. Wiśniewski (ed.). *Formy, osady i procesy subglacjalne. Symposium, Toruń – Górzno, 28–29 September 1994*. Toruń: Instytut Geografii Uniwersytetu Mikołaja Kopernika. 27–43.
31. Wysota W. 1995. Structure and mechanisms of drumlin formation in the glacial channels: a case study of the mid-eastern part of the Chełmno-Dobrzyń Lakeland. *Quaternary Studies in Poland.* Special Issue 13: 109–124.
32. Wysota W. 2004. Gliny morenowe bazalne w rdzeniu drumlinu Świerczynki 2, NE Pojezierze Dobrzyńskie. In: Wysota W. (ed.). *Gliny morenowe, typy genetyczne i środowiska depozycji*. Toruń: Uniwersytet Mikołaja Kopernika. 40–45.

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DRUMLINŲ PRIE ZBÓJNO (VIDURIO LENKIJA) KILMĖ

S a n t r a u k a

Drumlinai yra labai būdingi ledyniniam kraštovaizdžiui, todėl lengvai identifikuojami tiek topografiniuose žemėlapiuose, tiek ir gamtoje. Lenkijos teritorijoje drumlinai studijuojami daugiau kaip 100 metų. Zbójno (Vidurio Lenkija) apylinkėse esantis drumlinų laukas yra proksimalinėje Chrostkowo galinių morenų dalyje. Tai piečiausias toks rajonas Lenkijoje. Lauko plotas siekia apie 130 km^2. Drumlinų lauko vidurinės dalies fragmentas (30 km^2) buvo nuodugniai išnagrinėtas panaudojant georadarą ir gręžimo techniką. Zbójno drumlinai nėra tipiški. Jų ilgis dažnai siekia iki 500 m (65 %), bet yra ir ilgesnių nei 2000 m (12 %). Ilgiausias drumlinas yra 4393 m ilgio. Vyraujantis plotis 55–95 m. Šių ledyninių reljefo formų ilgosios keteros yra tarpusavyje lygiagrečios. Jų orientacija taip pat yra lygiagreti buvusiai ledyno slinkties krypčiai. Drumlinų struktūra paprastai yra trinarė: apatinis moreninis sluoksnis, fliuvioglacialinis branduolys ir viršutinis moreninis sluoksnis. Georadaru nustatyta apatinio moreninio sluoksnio glaciotektoninė deformacija, žyminti pradinę drumlinų formavimosi stadiją, t. y. protodrumliną. Drumlinų fliuvioglacialiniai branduoliai yra mažiau deformuoti negu žemiau slūgsanti morena. Atlikti tyrimai leido padaryti svarbią išvadą, kad ilgiems trinarės struktūros Zbójno drumlinams yra būdingos vidinės glaciotektoninės deformacijos. Suspaustas ir iškeltas aukštyn iki 3 m drumlinų vidinės dalies apatinis moreninis sluoksnis yra labiausiai deformuotas.

Петр Глебицки, Лешек Маркс

ПРОИСХОЖДЕНИЕ ДРУМЛИНОВ ОКОЛО ЗБУЙНО (ЦЕНТРАЛЬНАЯ ПОЛЬША)

Р е з ю м е

Для ледникового ландшафта друмлины весьма характерны и легко идентифицируются как на топографических картах, так и в натуре. Друмлины на территории Польши изучаются уже более 100 лет. Друмлиновое „поле“ в окрестностях Збуйно (Центральная Польша) является самым южным в Польше. Оно расположено в проксимальной части конечных морен Хростково. Площадь друмлинового поля достигает около 130 км^2. Фрагмент (30 км^2) центральной части друмлинового поля изучен детально с применением георадара и буровой техники. Изученные друмлины являются нетипичными. Их длина часто достигает 500 м (65 %), но встречаются и более длинные – до 2000 м (12 %). Самый длинный достигает 4393 м. Преобладающая ширина друмлинов – 55–95 м. Гребни этих форм рельефа параллельны друг другу, а также прежнему направлению движения ледника. Строение друмлинов обычно трехчленное и состоит из нижнего моренного слоя, флювиогляциального ядра и покрывающего верхнего моренного слоя. Изучение георадаром выявило гляциотектоническую деформацию нижнего моренного слоя, фиксирующую начальную стадию формирования друмлинов, т. е. протодрумлины. Флювиогляциальные ядра друмлинов менее деформированы по сравнению с нижезалегающей мореной. Исследования позволили сделать важное заключение о том, что изученные длинные друмлины трехчленной структуры характеризуются внутренней гляциотектонической деформацией. Вследствие сжатия в ледниковой среде наиболее сильно деформированный нижний моренный слой во внутренней части друмлинов обычно приподнят (до 3 м).