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PETROGRAPHIC ANALYSES AND INDICATOR ERRATICS OF GRAVELS OF THE ODRA LOBE

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Abstract
Fennoscandinavian erratics found in the glacial deposits till and in the glaciofluvial sediments within the main limit of the Odra glacier lobe (NW Poland and NE Germany), have been examined in two fractions: of 4–10 mm and 20–60 mm. The most numerous in the fraction of 4–10 mm are: crystalline rocks (Cr; 35–40%) originating in the Proterozoic Baltic Shield as well as Lower Palaeozoic limestones (LPL; 35–40%) – from the sedimentary sheet covering the Proterozoic Baltic Shield in the area of central Baltic Sea. Percentage of sandstones (S) amounts to 10–15%. The remaining rock types (several percent each) are: Palaeozoic shales (PS), the outcrops of which are localized in Scania (Skåne) and on Bornholm, Cretaceous limestones (CL) and flintstones (F) originating from the western part of the southern Baltic Sea as well as quartz (Q), milk quartz (MQ) and isolated grains of Devonian dolomites (DD).
From the analysis of indicator erratics, which was carried out in the 20–60 mm fraction, it appears that mainly the outcrops localized in Småland (*e.g.* red and grey Växjö granites, Påskallavik porphyries or Tessini and Kalmarsund sandstones) as well as in Scania (Höör and Hardeberga sandstones) and Region Blekinge–Bornholm (*e.g.* Karlshamn and Halen granites as well as Nexø and Bavnodde sandstones) had been subjected to the glacial plucking. Theoretical boulder centres (TBC, German: *TGZ das Theoretische Geschiebezentrum*, Lüttig 1958), which were calculated for 23 samples, are localized mostly in a small area in Småland, between 15°E–16°E and 56.5°N–58.5°N. Apart from indicator erratics the statistical ones are numerous, that are first of all grey and red Lower Palaeozoic limestones with their outcrops localized at the bottom of the central Baltic Sea. Taking into account the TBC values of indicator erratics as well as high percentage of statistical erratics it can be pronounced that the section of central and western Baltic Sea as well as the one of south-eastern Sweden had been subjected to the heaviest glacial plucking by that part of the Pleistocene ice-sheet which reached the studied area during the Pomeranian Phase.

Key words: petrography of glacial gravels, Scandinavian erratics, Pomeranian phase, Odra lobe, north-eastern Germany, north-western Poland

INTRODUCTION

The Pleistocene cooling of the climate resulted in the expanding Scandinavian ice-sheet which advanced more than once into the European Lowland area. The glacier was transporting and depositing rocks which first had been torn off from the bed of its route. Complex of erratics, especially of indicator ones (Meyer, Lüttig 2007), makes it possible to designate their source areas. They occur within the Pre-Cambrian Baltic Shield rich in crystalline rocks. They occur also in the plate covering this shield. The plate consists of sedimentary rocks of the Neoproterozoic, the Lower Palaeozoic, the Cretaceous period and the Palaeogene period (*e.g.* Ager 1980, Meyer 1983, Gaál, Gorbatschev 1987, Andréasson, Rodhe 1992, Bergström, Kornfält 1998, Scholz, Obst 2004, Bingen *et al.* 2008, Bogdanova *et al.* 2008, Hölttä *et al.* 2008, Lahtinen *et al.* 2008, Larsen *et al.* 2008, Minell 1980, Nøttvedt *et al.* 2008, Rasmussen *et al.* 2008, Wohlfarth *et al.* 2008). Determining the outcrops enables in turn to point out the prevailing directions of the distant glacial transport (*e.g.* Korn 1927, Gillberg 1965, Marcussen 1973, Minell 1980, Peltoniemi 1985, Salonen 1986, 1987, 1988, Dyke, Morris 1988, Stokes, Clark 1999), which are being used in palaeogeographical and stratigraphical deliberations. Such research proceedings will be presented here on the example of an analysis of the petrographic composition of gravels occurring in the Pleistocene deposits of so-called Odra glacier lobe (region B, Fig. 1). Hitherto this issue has been investigated in fragments, on small areas above all, and as a rule based on the data from geological drilling (*e.g.* Münnich 1932, Hesemann 1932, 1935, 1937, 1960, Rühberg, Krienke 1977, Krienke, Harff 1979, Choma-Moryl *et al.* 1991, Gogołek 1991a, b, 1992, 1993a, b, Masłowska, Michałowska 1994, Masłowska 1999).

During the last decade the first author was conducting in this area the petrographic research of gravels in a regional perspective. The examination was carried out on the material

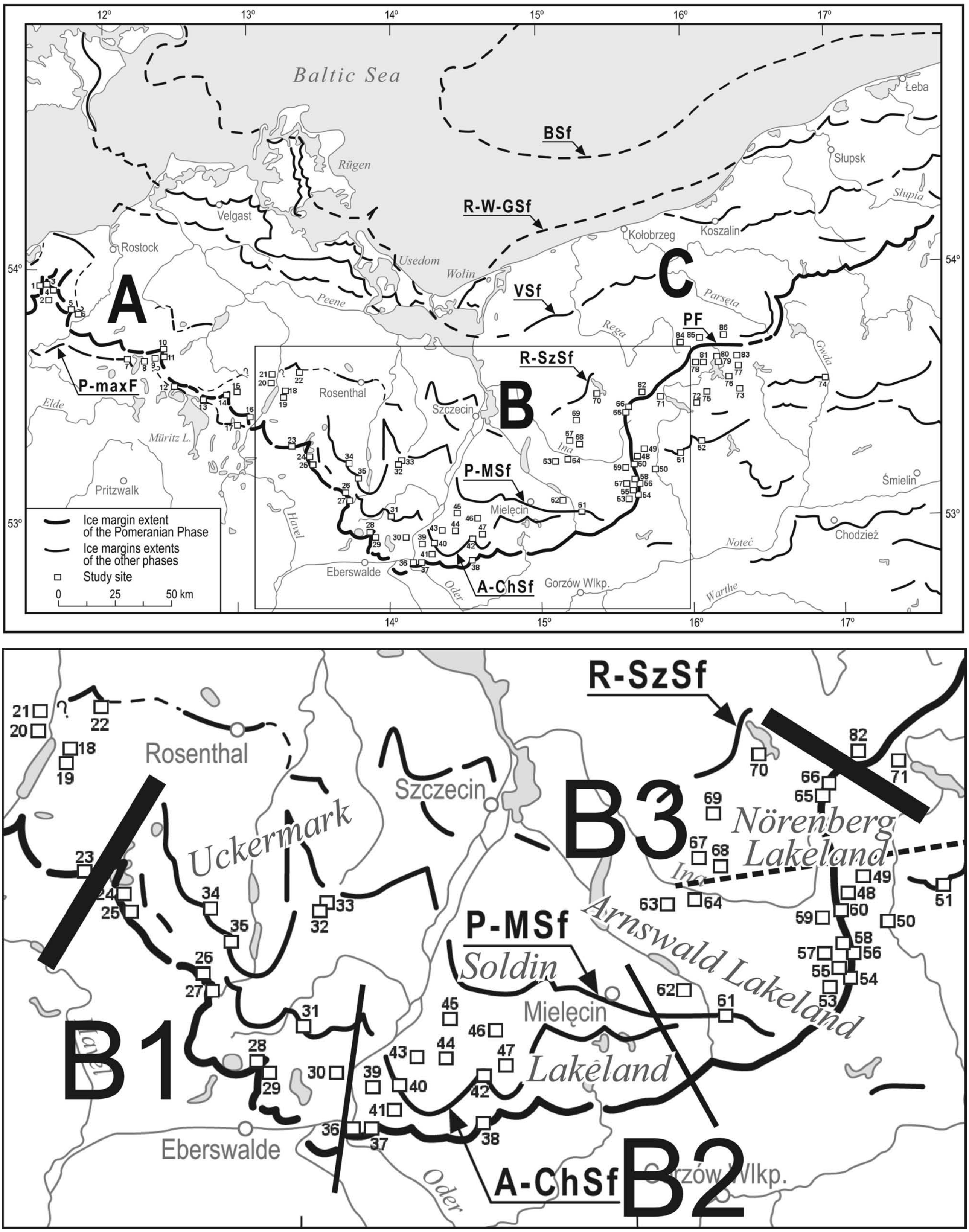

Fig. 1. Study area against the course of the maximum extent of the glaciomarginal Pomeranian Phase in NE Germany and NW Poland.

occurring both in the glacial tills and in the deposits of the glaciofluvial accumulation of the last glaciation Pomeranian Phase. The petrographic analysis of gravels of the 4–10 mm and 20–60 mm fractions as well as the analysis of indicator and statistical erratics were applied (Górska 1998a, b, 1999, 2000a, b, 2002a, b, 2003b, c, Górska-Zabielska 2008, Górska, Zabielski 2006, Górska-Zabielska, Stach 2008). The research was aimed not only at indicating the transport directions of the deposits but also at determining whether the potential differences in the petrographic composition between the deposits of the main limit of the Pomeranian Phase glaciation and its hinterland are statistically essential. Comparisons of that kind have not been undertaken so far.

RESEARCH AREA

The Odra Lobe (**region B**, Fig. 1; Keilhack 1904), where the fieldwork was conducted, is defined as a protruding part of main limit of the glaciation Pomeranian Phase (15.2 ^{14}C ka – Kozarski 1986, 1988, Marks 2002, 16.2 ka BP – Kozarski 1995, 14.8±0.4 ^{10}Be ka – Rinterknecht *et al.* 2005). In order to realize the scientific goal the area (Fig. 1) was divided into the following subregions:

- subregion **B1** – Uckermark:
  - glaciomarginal zone – sites 24–28;
  - hinterland – sites 29–35;
- subregion **B2** – the Myśliborskie Lakeland [Germ. *Soldiner Seenplatte*]:
  - glaciomarginal zone – sites 36–38;
  - hinterland – sites 39–47;
- subregion **B3** – the Choszczeńskie Lakeland [Germ. *Arnswalder Seenplatte*] and the Ińskie Lakeland [Germ. *Nörenberger Seenplatte*]:
  - glaciomarginal zone – sites 53–60 and 65, 66;
  - hinterland – sites 61–64 and 67–70.

Most of the research sites are situated in the glaciomarginal zone of the Odra Lobe and a part of them only in the glaciomarginal zones of the glacial retreat phases, that is the Parsteiner Subphase, Angermünde–Chojna, Zichow–Golmer and Gerswalde ones (Fig. 1; Woldstedt 1936, Markuse 1966, Karczewski 1969, Brose 1972, 1978, Cepek 1994).

Glaciomarginal zone of the Pomeranian Phase in this area is characteristic of diversified relief developed in the form of a distinct arch with the culmination reaching 180 m above sea level in the vicinity of Ińsko (*e.g.* Keilhack 1899, Schulz 1967, Liedtke 1981, 2001, Klump *et al.* 2002).

RESEARCH GOAL AND METHODS

The presented research was aimed at characterization of the petrographic composition features of the Odra Lobe gravels (4–10 mm and 20–60 mm fractions). The goal of the analysis of indicator and statistical erratics was to point out the areas of the Scandinavian ice-sheet dominant glacial plucking. During the Pomeranian Phase that glacier reached the Lower Odra River valley.

The presented issue is a fragment of some larger work (Górska-Zabielska 2008). The achieved results were used to investigate whether and to what extent the deposits differ (as far as the petrographic composition is concerned) from the deposits of the same age originating in the areas adjacent to the main research area from the west (Mecklenburg, **region A**) and the east (the Drawskie Lakeland, **region C**; Fig. 1).

Samples for petrographic analysis were taken both from the glacial till and from the glaciofluvial sediments. The gravels of 4–10 mm and 20–60 mm fractions were selected and analysed with special attention paid to the petrographic composition in accordance with the methodology applied among others by Böse (1989), Meyer (1985) and Lüttig (1995), and in the earlier works of the author herself (*e.g.* Górska 2000a, 2002a, b, 2003a, Górska-Zabielska 2007, 2008a). Each time the following types of rocks were allocated: Cr – crystalline rocks, LPL1 – grey Lower Palaeozoic limestones, LPL2 – red Lower Palaeozoic limestones, CL – Cretaceous limestones (Mesozoic), DD – dolomites, S – sandstones, LPS – Lower Palaeozoic shales, F – flintstones, Q – quartz and MQ – milk quartz.

The petrographic composition features of the 4–10 mm fraction were presented in the form of five petrographic indicators (coefficients): S/Cr, Cr/C, A/B, F/Cr, Q/Cr, where:

S – sum of percentage of sedimentary rocks (S, LPS, CL, LPL1, LPL2, DD);

C – sum of percentage of carbonate rocks (LPL1, LPL2, CL, DD);

A – sum of percentage of erosion non-resistant rocks (S, LPS, CL, LPL1, LPL2, DD);

B – sum of the percentage of erosion resistant rocks (Cr, F, Q, MQ).

Gravels of the 20–60 mm fraction were the object of analysis of indicator and statistical erratics, according to methodological principles and recommendations described *e.g.* by Lüttig (1958, 1991) and Meyer (1983) and by the author (MGZ) in her above quoted works.

PETROGRAPHIC COMPOSITION OF GRAVELS OF THE 4–10 mm FRACTION

Among ten petrographic types being allocated in gravels of the 4–10 mm fraction, crystalline rocks (Cr) are the most numerous in the glaciomarginal zone of subregions **B1** (41%) and **B3** (41.5%). On the other hand, percentage of Lower Palaeozoic limestones (LPL1+LPL2) is the biggest in gravels of the glaciomarginal zone and the **B2** hinterland (40.7%), as well as in gravels of the **B3** glaciomarginal zone (44.2%; Fig. 2).

The percentage of sandstones (S) is similar in all samples of the examined area and amounts on average to 14.7%. As a rule, population of the Lower Palaeozoic shales (LPS) is not numerous, however in the research area it is comparatively large and fluctuates from 7.6% in the **B1** gravels to 3.5% in the **B3** gravels. So big number of Palaeozoic shales in the 4–10 mm gravels of the Pomeranian Phase in Uckermark, was familiar already to Rühberg and Krienke (1977), who re-

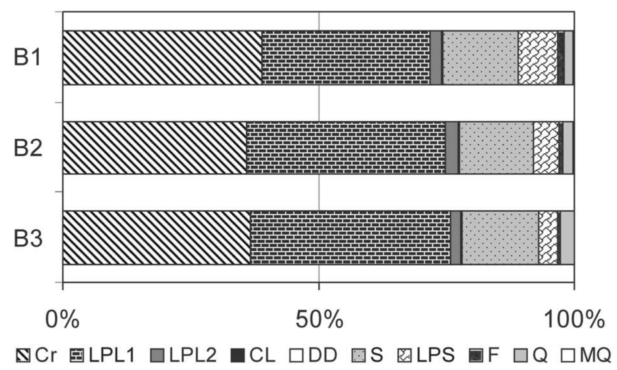

Fig. 2. Petrographical content of medium-coarse-gravel 4–10 mm derived from sediments of Uckermark B1, Soldin Lakeland B2 and Arnswald and Nörenberg Lakeland B3.

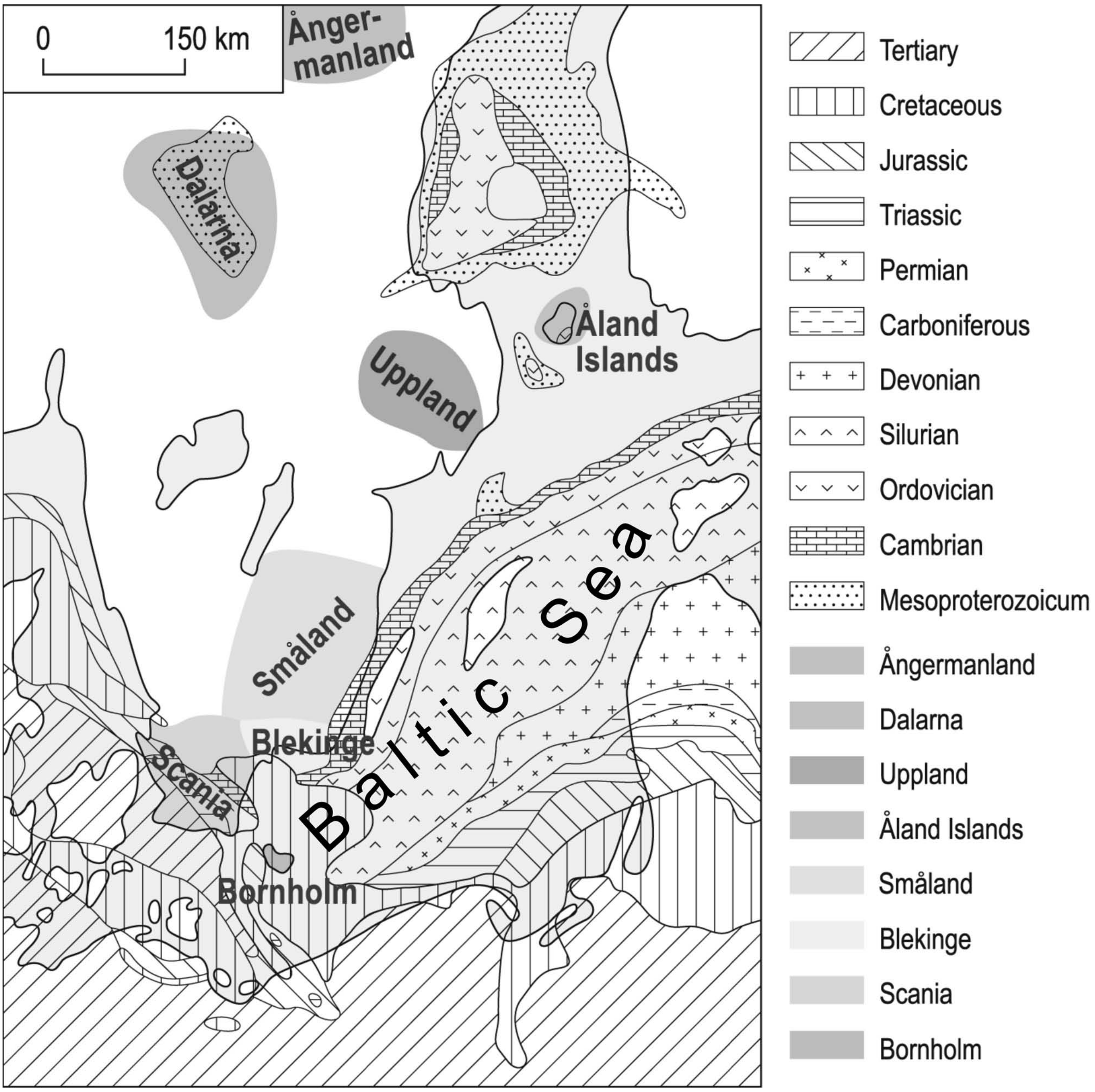

Fig. 3. Locations of main source regions of crystalline and sedimentary rocks – mother regions of indicator erratics (after Schulz 2003).

garded it as the typical petrographic feature of the glacial deposits correlated with the Pomeranian Phase in the Upper Odra River valley. The percentages of S and LPS reveal no diversification between the glaciomarginal zone and the hinterland.

The remaining petrographic types are not that abundant (Fig. 2). Quartz (Q) systematically, but to a very slight extent, increases its percentage from 1.9% in **B1** to 3.3% in **B3**, whereas flintstones (F) decrease from 1.2% in the **B1** gravels to 0.8% in **B3**. The lowest percentage of flintstones has been registered in the easternmost part of the research area (**B3**). The previous study (Górska-Zabielska 2008) in north-western Poland shows that in gravels of **region C**, situated east of the Odra Lobe, flintstones are not observed at all. However the distinctly bigger percentage of these rocks in the Pomeranian Phase sediments, is recorded westward in comparison with the Odra Lobe, that is in **region A**.

Because of scanty percentage of flintstones in gravels of the whole Odra Lobe (subregions B1, B2 and B3) it seems that the sediments of this area were deposited by the part of the ice-sheet which had not passed over the outcrops of flintstones. This scenario is different from that for the **region A**, where frequent flintstones indicate that the part of the glacier which reached Meklenburg must have moved over the outcrops of these rocks (Fig. 3).

In order to prove which petrographic features or petrographic indicators differentiate the subregions (B1, B2, B3) of the Odra Lobe, statistical analysis (non-parametric Mann-Whitney U test) was applied. The results of this test are presented in Table 1.

Table 1

Results of the U-Mann-Whitney test of petrographic types and coefficients in the analysed sediments in the mentioned regions B1, B2, B3

Variable	B1 (N=23) *vs* B2 (N=36)				B2 (N=36) *vs* B3 (N=58)				B1 (N=23) *vs* B3 (N=58)			
	Sum of rangs		$Z_{corr.}$	$p_{corr.}$	Sum of rangs		$Z_{corr.}$	$p_{corr.}$	Sum of rangs		$Z_{corr.}$	$p_{corr.}$
	B1	B2			B2	B3			B1	B3		
Cr	874	1404	1.215	0.224	1924	2829	-1.681	0.093	902	2024	0.187	0.852
LPL1	547	1731	-3.103	**0.002**	2190	2563	0.246	0.805	641	2285	-2.765	**0.006**
LPL2	784	1494	0.026	0.979	2380.5	2372.5	1.627	0.104	992.5	1933.5	1.210	0.226
CL	728.5	1549.5	-0.859	0.390	2389	2364	2.229	**0.026**	951	1975	1.066	0.287
DD	743.5	1534.5	-0.858	0.391	2255.5	2497.5	1.310	0.190	892.5	2033.5	0.169	0.866
S	831	1447	0.647	0.518	1999	2754	-1.138	0.255	829	2097	-0.639	0.523
LPS	1011	1267	3.024	**0.002**	2462	2291	2.217	**0.027**	1263	1663	4.268	**<0.001**
F	752.5	1525.5	-0.390	0.697	2513	2240	2.607	**0.009**	1052	1874	1.903	0.057
Q	697	1581	-1.122	0.262	1864.5	2888.5	-2.112	**0.035**	652.5	2273.5	-2.635	**0.008**
MQ	611	1667	-2.327	**0.020**	2193	2560	0.273	0.785	723.5	2202.5	-1.904	0.057
S/Cr	705.5	1572.5	-1.010	0.312	2370	2383	1.551	0.121	875	2051	-0.119	0.905
Cr/C	944	1334	2.139	**0.032**	2026	2727	-0.942	0.346	1008	1918	1.385	0.166
A/B	717	1561	-0.858	0.391	2385	2368	1.659	0.097	885	2041	-0.006	0.995
F/Cr	755.5	1522.5	-0.350	0.726	2518.5	2234.5	2.644	**0.008**	1058	1868	1.968	**0.049**

N – number of samples in compared groups, $Z_{corr.}$ – value of the corr. test, $p_{corr.}$ – level of significance calculated for $Z_{corr.}$; significant values are bolded

The 4–10 mm gravels within the Odra Lobe are characteristic of rather meagre variability of petrographic composition between individual samples (expressed in smaller number of differentiation variables), and usually insignificant differences between individual subregions. Gravels of the subregions **B1** and **B2** differ from each other in the content of grey limestones (LPL1) and Lower Palaeozoic shales (LPS), milk quartz (MQ) as well as in values of the petrographic indicator Cr/C. Gravels of the subregions **B2** and **B3** are also diversified in terms of not numerous petrographic types (Cretaceous limestones (CL), Palaeozoic shales (LPS), flintstones (F) and quartz (Q)) as well as of petrographic indicator F/Cr, while subregions **B1** and **B3** are distinguished by grey limestones (LPL1) and Lower Palaeozoic shales (LPS), quartz (Q) as well as by petrographic indicator F/Cr.

In light of similar study conducted on 4–10 mm gravels from the adjacent areas: Meklenburg (**region A**) to the west, and Drawskie Lakeland (**region C**) to the east, it turned out that the differences among the regions A, B and C were very essential (Górska-Zabielska 2008). This is a distinct sign of the petrographic identity of the Odra Lobe gravels in comparison with the neighbouring areas, and it proves a kind of the petrographic composition uniformity within the Odra Lobe itself.

ANALYSIS OF INDICATOR ERRATICS

The presented research proved that indicator erratics of the Odra Lobe deposits originate first of all in two Scandinavian source areas (Småland and Scania–Blekinge–Bornholm), both localized in the south-eastern Sweden.

Erratics from Småland are the most numerous, including (Fig. 4) the typical red Småland granites [1] (the number corresponds to the localization of the Scandinavian outcrop in Fig. 4) as well as red [2] and grey [3] Växjö granites. Vånevik granites [4] are next to occur. They are often accompanied by Småland rhyolites, for example Påskallavik porphyries [5] or Emarp porphyries [6]. The highest percentage of crystalline

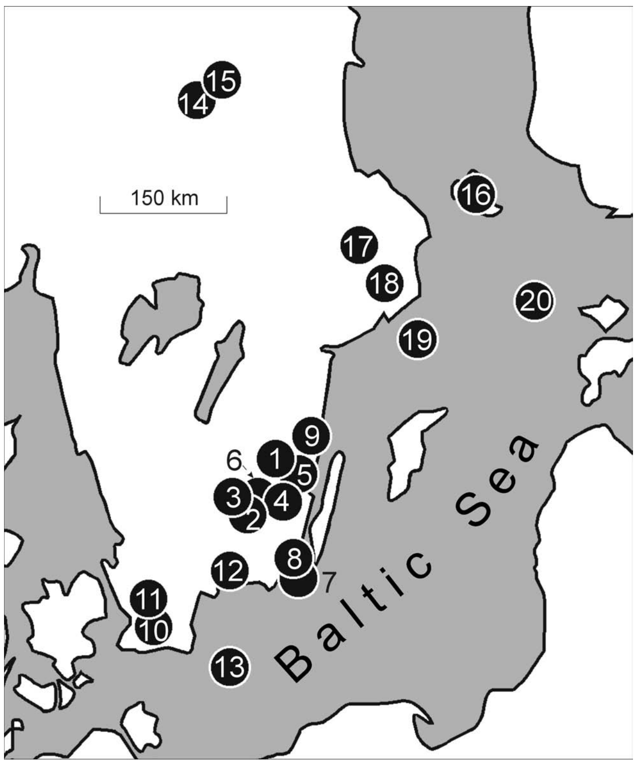

Fig. 4. Locations of the outcrops of rocks, which later, as indicator erratics, were derived from sediments in the study area. Number explanations in text.

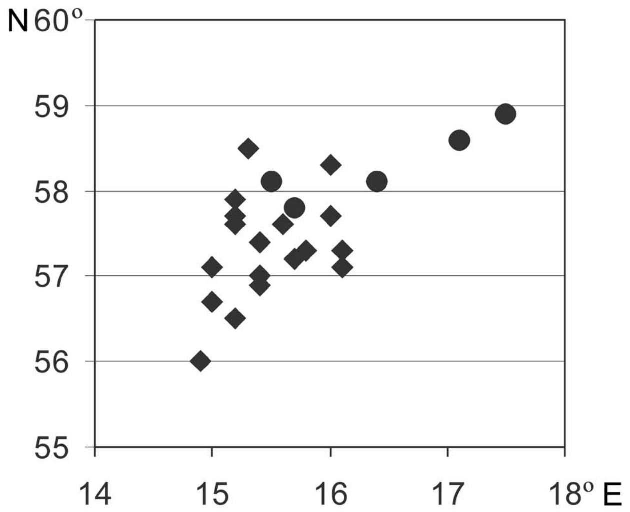

Fig. 5. Location of teoretical boulder centres TBC of the indicator erratics: 1 (◆) – within the main exaration area (samples taken from the glaciomarginal zone of the Odra lobe), 2 (●) – outside the main exaration area (samples taken from the Ange- rmünde–Chojna recessional zone in the Soldin Lakeland).

erratics from Småland was determined in samples from Götschendorf (site No 27 in Fig. 1), Althüttendorf (28), Golice (37), Strzelczyn (46) and Trzcińsko Zdrój (47).

Moreover in the examined deposits of the Odra Lobe some erratics of the sedimentary rocks were also found (including quartzites as well). The most frequent of them are Kalmarsund sandstones [7], Tessini sandstones [8] and Västervik quartzites [9]. The sedimentary erratics are more frequent in the German part of the research area (*e.g.* Althüttendorf (site No 28 in Fig. 1), Buchholz (35), than in the Polish one.

In gravels of the Odra Lobe, erratics from the parent Scania–Blekinge–Bornholm area are observed everywhere. First of all these are Hardeberga sandstones [10] and Höör sandstones [11]. They occur in all 23 samples of the Odra Lobe gravels. Isolated Karlshamn granites from Blekinge [12] (*e.g.* Chełm Górny – site No 38 in Fig. 1) as well as granites from Bornholm [13] (*e.g.* in Nawodna – 45, Golice – 37, Strzelczyn – 46) were determined. Magmatic indicator erratics are definitely less frequent in the whole region.

Great distance between the deposition area and the source area may be the cause why the rocks from Dalarna (*e.g.* Dalarna porphyry [14], Grönklitt porphyrite [15]) seldom appear among indicator erratics of the Odra Lobe. It is also possible that the less frequent occurrence would be associated with the youngest ice-stream. In the Upper Vistulian this Baltic Ice-stream was advancing from the Baltic Sea region, and bypassing central Sweden. Such a process was earlier suggested by Kjær *et al.* (2003).

Åland granites and porphyries [16] show themselves in little amounts in the investigated samples. 1–3 examples is an average number of these erratics in a sample. Most of the Åland erratics were found in subregion **B2** (*e.g.* sites Chełm Górny – site No 38 in Fig. 1, Łaziszcze – 39, Nawodna – 45, Strzelczyn – 46, Trzcińsko Zdrój – 47). Not a single erratic from the Åland Islands was determined in originating within the main limit of the Pomeranian Phase of subregion **B3**.

Furthermore, in the analysed coarse-grained gravels of the Odra Lobe some individual examples of indicator erratics were noticed. These are the examples from the outcrops in Uppland (Uppsala granite [17], Stockholm granite [18]) as well as from the outcrops of central Baltic Sea (dark brown [19] and red Baltic porphyry [20]).

Basing on analysis of the Scandinavian erratics for each sample of the coarse-grained gravels, the Theoretical Boulder Centre TBC (German: *TGZ*, Lüttig 1958) was calculated. TBCs of the majority of the Odra Lobe indicator erratics occur in the comparatively compact area between 14.8°E–16.5°E and between 56.5°N–58.5°N, so they are placed exclusively in Småland (black diamonds in Fig. 5). It is a proof of the effective glacial plucking in south-eastern Sweden. That is not the only area on the southward transgression route of the glacier during the Pomeranian Phase. Presence of statistical erratics indicates that the ice-sheet moved over other outcrops as well.

Distant from the area presented above are the theoretical boulder centres TBC calculated for five samples of the subregion **B2** gravels (black circles in Fig. 5). These gravel samples were taken in the retreat zone of the Angermünde–Chojna Subphase (Kozarski 1965, Dobracka, Piotrowski 2003).

ANALYSIS OF STATISTICAL ERRATICS

Apart from indicator erratics the erratic material of the 20–60 mm fraction from the research area encompasses also statistical erratics. The most numerous group among them constitute Lower Palaeozoic limestones; their percentage fluctuates in the 30–40% range. Sandstones are the second group as regards the number (15–25% on average). Statistical erratics include also flintstones (2–3% on the whole), rarely occurring Cretaceous limestones as well as Palaeozoic shales, appearing in the Uckermark gravels solely. As a rule quartz does not show itself in the fraction of 20–60 mm (Schulz 1973).

Besides statistical erratics there are undetermined crystalline rocks in the erratic material. These rocks may theoretically originate from all over the Baltic shield. They make around 30–40% of all analysed coarse-grained gravels. The number of these erratics is in inverse proportion to the number of Lower Palaeozoic limestones.

SUMMARY

The conducted research indicated which rocks are the most numerous among gravels of the 4–10 mm fraction in three subregions (B1, B2, B3) of the Odra lobe. These are crystalline rocks (Cr) and Lower Palaeozoic limestones (LPL1), percentage of which in both cases amounts to about 40% in the examined samples. The third petrographic type as regard the number are sandstones (S), percentage of which comes on average to 15%. The remaining petrographic types occur up to few percent each: Lower Palaeozoic shales (LPS) from 7.6% in Uckermark to 3.5% in the Choszczeńskie and Ińskie Lakelands, quartz (Q) – 1.8–3.3% respectively and flintstones (F) – 1.2–0.8% respectively.

The statistical analysis proved that the petrographic compositions of the B1, B2 and B3 subregions differ essentially, concerning only:

1. content of grey limestones and Lower Palaeozoic shales, milk quartz as well as the petrographic indicator Cr/C in gravels of Uckermark (**B1**) and Myśliborskie Lakeland (**B2**),

2. less numerous petrographic types such as Cretaceous limestones, Lower Palaeozoic shales, flintstones and quartz as well as their derived petrographic indicators (F/Cr), which differentiate gravels of the Myśliborskie Lakeland (**B2**) and the Choszczeńskie/Ińskie Lakelands (**B3**),

3. grey limestones and Lower Palaeozoic shales, quartz as well as two petrographic indicators: F/Cr, due to which the subregions Uckermark (**B1**) and the Choszczeńskie/Lakelands (**B3**) differ.

The analogous statistical analysis comparing the main regions A, B and C (Górska-Zabielska 2008) showed more significant differences of petrographic composition features between the regions than within the region B (the Odra lobe) itself. Hence it seems reasonable to suggest a close petrographic similarity of gravels of the 4 – 10 mm fraction in the Odra Lobe deposits.

Analysis of the 20–60 mm gravels showed that the Småland granites are the most frequently identified indicator erratics. They are accompanied with sandstones or quartzites from the same source area. Large group of indicator erratics originates from region of Scania–Blekinge–Bornholm. Also erratics from Dalarna in central Sweden occur quite often. Åland erratics, although easily identified, appear in isolated amounts. Occasionally, indicator erratics originating in the outcrops of Uppland and in the bottom of central Baltic Sea are also found.

Theoretical boulder centres (TBC) of most indicator erratics in the Odra Lobe are localized in the compact area within Småland. Gravels deposited during the Angermünde–Chojna retreat glacier phase must have been subjected to the glacial plucking in the Scandinavian outcrops other than the gravels of the main advance of the ice-sheet in its Pomeranian Phase. It is proved by their theoretical boulder centres situated to the northern east of Småland.

Summing up, it can be concluded that the part of the Scandinavian ice-sheet responsible for the Odra Lobe formation in the Upper Pleni-Vistulian, at first must have been moving over the outcrops of rocks in south-eastern Sweden and western part of central Baltic Sea. Considering the number of erratics originating from the outcrops of mentioned areas, one arrives at a conclusion that exaration was the biggest there. It is obvious that frequent occurrence of rocks could be caused by a large area of outcrops as well as by their bigger susceptibility to the weathering which made the incorporation process into an ice-sheet easy.

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