Geological Quarterly, 2006, **50** (2): 239–246

Petrographic characteristics of fluvioglacial deposits of the Odra lobe, Poland: a statistical analysis

Maria GÓRSKA and Ryszard ZABIELSKI

Górska M. and Zabielski R. (2006) — Petrographic characteristics of fluvioglacial deposits of the Odra lobe, Poland: a statistical analysis. Geol. Quart., **50** (2): 239–246. Warszawa.

The fluvioglacial deposits of the Odra lobe, laid down during the Pomeranian phase of the last glaciation in northeastern Germany and northwestern Poland, have been analysed petrographically and interpreted in a regional perspective. The deposits have been classified in terms of the percentage of 10 selected petrographical groups and 5 petrographical coefficients. Statistical analysis of their values has shown significant petrographic differences that relate to the morphological characteristics of the study area. The greatest petrographic diversity was observed between Mecklenburg–Western Pomerania and the Odra lobe as well as between the Odra lobe and middle Pomerania. The differentiating features are: crystalline rocks, grey Palaeozoic limestones and flints and all of the petrographical coefficients. The differences within the Odra lobe itself are small by comparison with those in the neighbouring regions. They are the most evident between Uckermark and the Myśliborskie Lakeland. The differentiating features are: flints and quartz as well as a maximum of four out of five petrographical coefficients.

Maria Górska, Institute of Palaeogeography and Geoecology, Adam Mickiewicz University, Dzięgielowa 27, PL-61-680 Poznań, Poland, e-mail: gorska@man.poznan.pl; Ryszard Zabielski, Polish Geological Institute, Rakowiecka 4, PL-00-975 Warszawa, Poland, e-mail: ryszard.zabielski@pgi.gov.pl *(received: August 1, 2005; accepted: February 8, 2006).*

Key words: Odra lobe, fluvioglacial deposits, petrographical composition, statistical analysis.

SHORT HISTORICAL OUTLINE

The region of the Odra lobe has attracted scientific interest for more than 100 years (Keilhack, 1897, 1899, 1904; Hesemann, 1932). This part of a more extensive group of glaciomarginal features of the Pomeranian phase of the last glaciation is located in north-east Germany (NE Brandenburg–Uckermark) and northwestern Poland (Fig. 1). Questions tackled by previous research have included attempts at explaining the characteristic curved (arch-like) course of this piece of the glaciomarginal zone. The probable reasons for such a shape were mainly explained by in terms of the geological structure and morphology of the bedrock, which was covered later by the Pomeranian ice sheet (e.g. Hannemann, 1970; Kopczyńska-Żandarska, 1970; Karczewski, 1989, 1996; Piotrowski, 1991*a*, *b*, 1999; Kurzawa, 1999, 2000, 2001). More recently, the influence of surge processes on the genesis of the Odra lobe has became a possibility, as such a mechanism has been proposed for adjacent regions, i.e. for the Parsęta lobe, located to the east (Jania and Bukowska-Jania, 1997). Previous petrographic studies of the gravels of the glacial tills and fluvioglacial deposits of the Odra lobe area have been limited to analyses of material from a few boreholes, or, rarely from exposures. The data produced allowed only limited regional correlations to be undertaken.

Studies of the petrographic composition of the glacial tills and the fluvioglacial deposits of the Odra lobe date back to the 1930's (Münnich, 1932; Hesemann, 1932, 1960; Mojski, 1968), and were used to characterize deposits relating to the Pomeranian phase of the last glaciation. These early interpretations now need to be reassessed. Coarse material has been examined without taking into consideration its derivation from different geomorphological units such as eg.: the glaciomarginal zone or the hinterland. Neither have these petrographical features of the glacial tills and the fluvioglacial deposits occurring in the Odra lobe been compared with the corresponding deposits occurring to the west and to the east of the lobe. The analysis of the petrographical composition of the fluvioglacial deposits which may account for the supplement to the researches commonly conducted as far as the glacial tills are concerned has been passed over entirely in the researches area literature (Górska, 2003*c*; Rutkowski, 1999, 2006).

The remaining papers in the field of petrography of the glacial tills and the fluvioglacial deposits of the discussed area con-

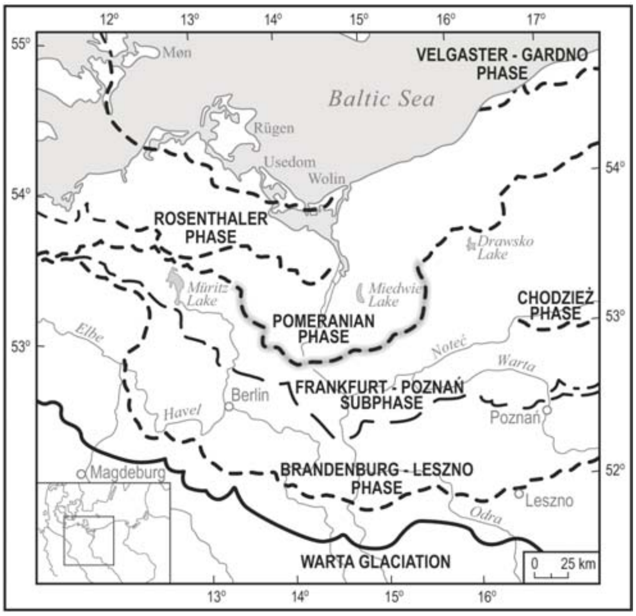

Fig. 1. Location of the ice-front Odra lobe (grey dashed line) of the Pomeranian phase, and ice limits of relevant phases of the Scandinavian icesheet in NW Poland and NE Germany (Smed, 2002, changed)

sist of the analytical studies and were associated with the production of the Polish and German geological maps. These studies (eg. Cepek, 1962, 1969, 1973, 1975; Schulz, 1964, 1968; Rühberg, 1987, 1999; Piotrowski 1990*a*, *b*, 1991*a*, *b*, 1996, 1999; Masłowska and Michałowska, 1994, 1995; Masłowska, 1999) were documentary kind rather than synthetic

More recently, research into the Odra lobe in Poland and in Germany has been undertaken (Górska, 2002*a–f*, 2003*a*, *b*, 2004, 2006; Górska *et al*., 2001, 2002; Górska and Stach, 2006, in prep.). They were aimed at characterizing the petrographic composition of tills and of fluvioglacial deposits derived from the main part of the Pomeranian ice sheet, and from its foreland and the hinterland. It is hoped that such research might identify petrographic features that could distinguish the sediments of the Odra lobe from the contemporary sediments of the adjacent regions, deposited during the Pomeranian phase advance.

METHODS

Analysis of the petrographic composition of the gravel fraction primarily figure material derived from glacial till. However, such analyses have also been carried out on fluvioglacial, periglacial and fluvial deposits (Schulz, 1961; Wiśniewski, 1971; Lüttig, 1991, 1999; Meyer, 2000; Rutkowski, 1999, 2003, 2006). Because these are common in the area studied we decided to conduct research into fluvioglacial material, in which adequate sampling is easier.

The lack of any regional synthesis, of the results of petrographical analyses of gravels (4–10 mm) and coarse gravels (20–60 mm) of fluvioglacial deposits of the Odra lobe has stimulated research into this area in both Poland and Germany. In this paper, we stress the significance of statistical analysis of selected petrographic features of the 4–10 mm fraction. The petrographical composition varies, which is a consequence of geology of alimentation and transition zones and probably different style of glacial transport. Statistical analysis shows, which petrographic groups or coefficients characterize particular regions; which differences are significant; and whether the compositional differences reflect the development of morphological elements of the lobe.

The results of our statistical analysis, when combined with those of published studies, will allow a full synthesis of the genesis of the Odra lobe to be given.

158 samples have been taken in 75 study sites, located more or less evenly along the glaciomarginal zone of the Pommeranian phase (Fig. 2, Appendix A). Samples were collected in three regions:

A — Meklemburg-Front Pomerania (29 samples from 22 sites: 1–22);

B — Odra lobe;

B1 — western part, Uckermark, Germany (9 samples from 5 sites: 23–27);

B2 — middle part, Myśliborskie Lakeland, Poland (23 samples from 11 sites: 28–38);

B3 — eastern part, Choszczeńskie Lakeland, Poland (48 samples from 20 sites: 39–58);

C — middle Pomerania (49 samples from 17 sites: 59–75).

These areas were chosen due to changes in the position of the glaciomarginal zone and the distribution of geographical regions (Kondracki, 1968, 2000; Liedtke and Marcinek, 1994).

In the petrographic analysis of the gravels (4–10 mm) of the fluvioglacial deposits the research methods used follow those of earlier studies (Górska, 2000, 2006). Material from the fluvioglacial deposits sampled were divided into 10 petrographic groups: Kr — crystalline rocks, Wp1 — grey Silurian and Ordovician limestones, Wp2 — red Ordovician limestones, Wk — Cretaceous limestones, D — dolomites, Pp — Palaeozoic sandstones, Łp — Palaeozoic slates, Krz — flints, Q — quartz, Qml — milky quartz. On their basis 5 petrographic coefficients were calculated: O/Kr, Kr/W, A/B, Krz/Kr, Q/Kr, where:

O — sum of Pp, Łp, Wk, Wp1, Wp2, D;

W — sum of Wp1, Wp2, D;

A — sum of Pp, Łp, Wk, Wp1, Wp2, D;

B — sum of Kr, Krz, Q, Qml.

These petrographic groups and coefficients may, statistically, be treated as variables. Standard statistical parameters of variables are given in Appendices B–F.

The research proceeded in two stages. Stage I separated the petrographic features of the fluvioglacial deposits of the Odra lobe from those of neighbouring areas. Stage II aimed to identify petrographic features within the Odra lobe that reflect the foreland, the marginal zone and the hinterland.

Stage II will be published separately, and the stage I results are published here.

A statistical test was used to estimate differences, or lack of them, between the petrographic variables. It is important to choose an appropriate test. The *t*-Student's test is commonly used to evaluate the differences in means between two groups. Theoretically, the *t*-test can be used even if the sample sizes are very small as long as the variables are normally distributed within each group and the variation of scores in the two groups is not reliably different. If these conditions are not met, then the differences in means between two groups can be evaluated us-

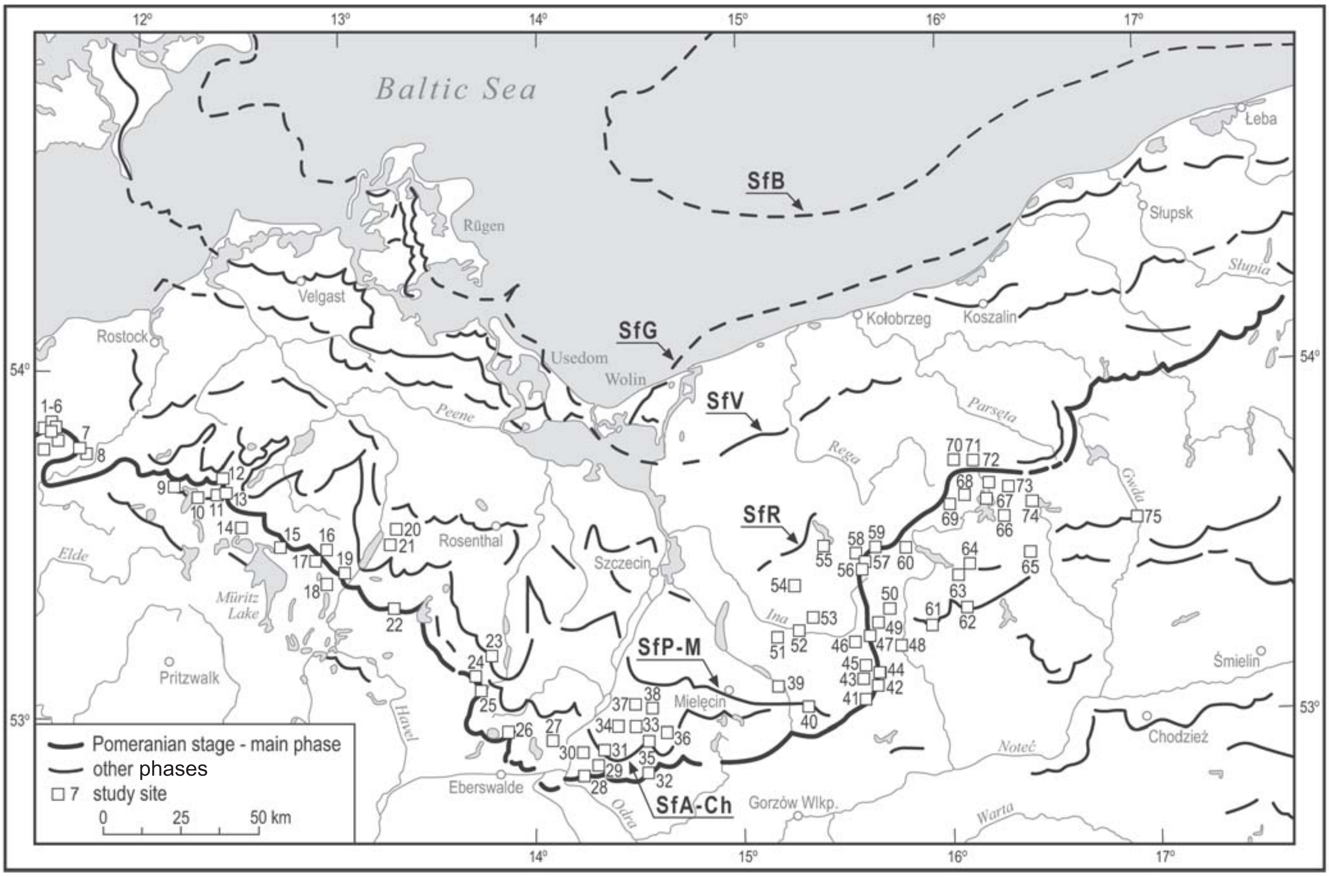

Fig. 2. Location of study sites in the Odra lobe and adjacent regions within the extent of the Pomeranian phase (after Liedtke, 1981; Kliewe and Kozarski 1979; changed)

SfA-Ch — subphase Angermünde–Chojna, SfP-M — subphase Penkun–Mielęcin, SfR — subphase Rosenthal, SfV — subphase Velgast, SfG — subphase northern Rügen–Wolin–Gardno, SfB — subphase Bornholm

ing one of the nonparametric alternatives to the *t*-test, for example the *Mann-Whitney U*-test.

The interpretation of the test is essentially identical to the interpretation of the result of a *t*-test for independent samples, with the exception that the *U*-test is computed on the base on rank sums. The *U*-test is the most powerful (or sensitive) nonparametric alternative to the *t*-test for independent samples. The results of the test are presented in Appendices G and H. The most important feature for interpretation of the test is the *p*-value; this represents the probability of error involved in accepting the hypothesis about the existence of a difference. Commonly in science, so called critical value (α) is fixed on 0.05 or 0.1 (in this paper $\alpha = 0.05$). When $p < \alpha$, it means that differences between variables (e.g. percentage content of crystallines) are significant and that samples are derived from two statistically varied populations. Comparable analyses have recently been made by Zabielski (2000, 2004), of the petrographic composition of gravels from tills in the Konin region.

INTERPRETATION

Between the Odra lobe (region B) and the adjacent regions: A (Mecklenburg–western Pomerania) and C (middle Pomerania) there are the significant differences in the petrographic composition of the 4–10 mm fraction gravels. This is seen in the variables (features) Kr, Wp1, Krz, Q as well as in all the petrographical coefficients (Appendix G). However, the differences between the regions A and C are marked for a smaller number of variables — primarily for Wk, Krz, (Wp1 is borderline as far as significance is concerned — Appendix G) as well as for the coefficients Krz/K and Q/Kr. The statistical parameters of the selected variables (Kr, Wp1, O/K) are shown graphically in the form of "box and whisker" graphs (Fig. 3).

Differences in petrographic content appear also within the regions of the Odra lobe (between B1 and B2 or B2 and B3; Appendix H, Fig. 4), but they are less significant than in the adjacent regions. Content of Krz (flints) is at least three times smaller in the lobe than in the A region and Q also dominates in the eastern part of the lobe (B3) and in middle Pomerania (C). Values of petrographic coefficients have significant differences mainly between subregions B1 and B2 (Appendix H). Only Q/Kr has similar values. On the other hand it is the only coefficient differentiating the central from the western part of the Odra lobe (B2 and B3, Appendix H).

From the statistical comparisons presented above, it is clear that the petrographic content of the 4–10 mm fraction of the Odra lobe fluvioglacial deposits, recorded as petrographic

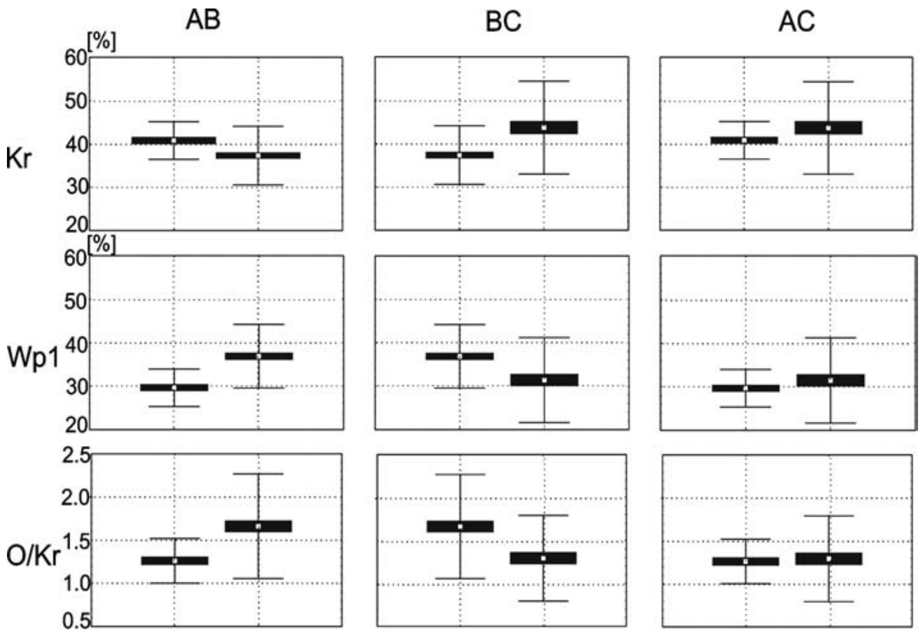

Fig. 3. "Box and whisker" graph for the percentage of crystalline rocks Kr and grey Lower Palaeozoic limestones Wp1 as well as for the values of the petrographical coefficient O/Kr of the 4–10 mm fraction in the regions AB, BC and AC

Error bars — standard deviation, bold bar — standard error, small quadrangle — average value

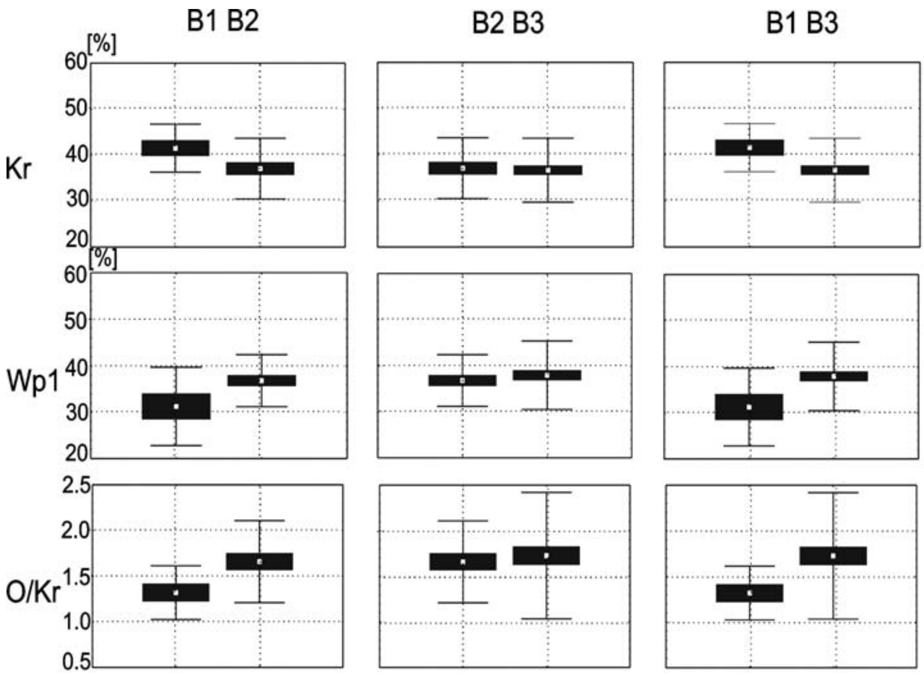

Fig. 4. "Box and whisker" graph for the percentage of the crystalline rocks Kr and grey Lower Palaeozoic limestones Wp1 as well as for the values of the petrographical coefficient O/Kr of the 4–10 mm fraction in subregions B1B2, B2B3, B1B3; for other explanation see Figure 3

groups and coefficients, shows differentiation between regions A, B and C and within the lobe (B1, B2, B3). This is seen as significance levels of difference (p corr., see Appendices G and H). They are different within the region of the Odra lobe and the adjacent regions.

Regions A, B, C are characterized by a strong differentiation of petrographic features. Subregions B1, B2, B3 show weaker differentiation. This is seen in the smaller number of differing variables and by the lower value of significance of the differences (p corr., Appendices G and H). Hence on that basis it is possible to reveal a presumed relationship between the features of the petrographic composition of the 4–10 mm gravel fraction and the geomorphological units in the research area analysed. This might be connected with the various mechanisms of sediment transport in the ice sheet zone which formed the Odra lobe. Obviously, on the basis of the features of the petrographic composition of the deposits of only one facies, it is difficult to unambiguously show their origins with respect to the diverse dynamics of the ice sheet in the research area. The results of more comprehensive research would further illuminate this issue.

Acknowledgments. We thank M. Gościnska, M.Sc. for drawing the Figures 1 and 2, Dr. A. Stach (A. Mickiewicz University, Poznań) for discussion, Dr. D. Gałązka (Polish Geological Institute, Warsaw) and Dr. P. Czubla (University of Łódź) for constructive remarks and H. Kossak-Nowocień, M.Sc, for the English translation. The research has been financed by grants DAAD A/99/06440 and KBN 6 P04E 015 21.

REFERENCE

CEPEK A. G. (1962) — Zur Grundmoränenstratigraphie in Brandenburg. Ber. deutsch. Ges. geol. Wiss., Serie B, **7** (2): 275–278.

CEPEK A. G. (1969) — Zur Bestimmung und stratigraphischen Bedeutung der Dolomitgeschiebe in den Grundmoränen im Nordteil der DDR. Geologie, **18** (6): 657–673.

CEPEK A. G. (1973) — Zur stratigraphischen Interpretation des Quartärs der Stoltera bei Warnemünde nach neuen Geschiebeanalysen. Zeitsch. Geol. Wiss., **1** (9): 1155–1171.

CEPEK A. G. (1975) — Zur Stratigraphie des Quartärs in den Kliffprofilen nördlich Saßnitz/Rügen. Wiss. Zeitsch. EMA Uni, Greifswald, **24** (3/4): 171–174.

GÓRSKA M. (2000) — Some petrographical features of Vistulian lodgement till in the central and southern Wielkopolska Lowland and their significance towards estimating the dynamics of the last ice sheet (in Polish with English summary). Prace PTPN, **28**.

GÓRSKA M. (2002*a*) — The petrography of glacial sediments in Uckermark and Soldin Lakeland. DEUQUA 2002, Potsdam, 26–31.08.02. Terra Nostra: 116–119.

GÓRSKA M. (2002*b*) — Petrografia osadów akumulacji lodowcowej Pojezierza Drawskiego. IX Konferencja "Stratygrafia plejstocenu Polski", Plejstocen Pomorza Środkowego i strefa marginalna lobu Parsęty. Streszczenia referatów. Borne Sulinowo, 3–7.09.02, **23**.

GÓRSKA M. (2002*c*) — Petrografia osadów lodowcowych Uckermark, pn.-wsch. Brandenburgia. VI Zjazd Geomorfologów Polskich "Środowiska Górskie — Ewolucja Rzeźby", Jelenia Góra 11–14.09.02. Streszczenia referatów i posterów: 50–51.

GÓRSKA M. (2002*d*) — Narzutniaki skandynawskie Pojezierza Myśliborskiego. VI Zjazd Geomorfologów Polskich "Środowiska Górskie — Ewolucja Rzeźby", Jelenia Góra 11–14.09.02. Streszczenia referatów i posterów: 52–53.

GÓRSKA M. (2002*e*) — Petrographie von uckermärkischen Geschieben. Geologische Brandenburgische Beiträge, Neubrandenburg, **3**: 35–47

GÓRSKA M. (2002*f*) — Petrography of till and fluvioglacial deposits in the Drawa Lakeland (in Polish with English summary). Bad. Fizjograf. Pol. Zach., Poznań, Ser. A, **53**: 29–42.

GÓRSKA M. (2003*a*) — Petrography of glacial sediments in Uckermark, NE Brandenburg — a preliminary study. Landform Analysis, **4**: 39–48.

GÓRSKA M. (2003*b*) — Narzutniaki skandynawskie Pojezierza Myśliborskiego. Streszczenia referatów i posterów. IV Seminarium Geneza, litologia i stratygrafia utworów czwartorzędowych, Poznań, 13–14.10.2003: 12–14

GÓRSKA M. (2003*c*) — Petrographic analysis of Scandinavian erratics (in Polish with English summary. In: Analizy sedymentologiczne osadów glacigenicznych (eds. M. Harasimiuk and S. Terpiłowski): 23–31. Wyd. UMCS, Lublin.

GÓRSKA M. (2004) — Petrography of glacial sediments in Pojezierze Myśliborskie (Myśliborskie Seenplatte). 71. Tagung der Arbeitsgemeinschaft Norddeutscher Geologen, 1-4.06.2004, Frankfurt/Oder: 55.

GÓRSKA M. (2006) — Scandinavian erratics — methodics and interpretation (in Polish with English summary). In: Badania cech teksturalnych osadów czwartorzędowych i wybrane metody oznaczania ich wieku (eds. E. Mycielska-Dowgiałło and J. Rutkowski). Wyd. WSRiG, UW, Warszawa (in print).

GÓRSKA M., MEYER K.-D., RUTKOWSKI J. and SKOCZYLAS J. (2001) — Preliminary results of the control determination of the quartzites of the Scandinavian and local origin from Poland (in Polish with English summary). Geneza, litologia i stratygrafia utworów czwartorzędowych, t. 3. Geografia **64**: 175–186.

GÓRSKA M., PIOTROWSKI A. and DOBRACKI R. (2002) — Soldin Seenplatte — geology, lithostratigraphy and petrography of glacial deposits. DEUQUA 2002, Exkursionsführer: 104–123.

HANNEMANN J. (1970) — Grundzüge der Reliefentwicklung und der Entstehung von Grossformen in Jungmoränengebieten Brandenburgs. Petermanns Geographische Mitteilungen, **2**: 103–116.

HESEMANN J. (1932) — Zur Geschiebeführung und Geologie des Odergletschers. 1. Äussere, Rosenthaler und Velgaster Randlage. Jahrb. d. preuss. geol. Landesanst., **53**: 70–84.

HESEMANN J. (1960) — Geschiebeforschung im Rück- und Ausblick. Berichte der Geolog. Gesellsch. in der DDR., **5**: 191–205.

JANIA J. and BUKOWSKA-JANIA E. (1997) — Model procesów paleoglacjalnych fazy pomorskiej vistulianu w obrębie lobu Parsęty na podstawie badań obszarów aktualnie zlodowaconych. In: Studia nad środowiskiem geograficznym Bornego Sulinowa (eds. E. Bukowska-Jania and M. Pulina): 27–57. PWN, Warszawa.

KARCZEWSKI A. (1989) — Morphogenesis of the Pomeranian Phase marginal zone in the Parsęta Lobe region in the Vistulian (Middle Pomerania) (in Polish with English summary). Geografia, **44**.

KARCZEWSKI A. (1996) — Morpho- and lithogenetic diversification of the Pomeranian Phase in western and central Pomerania (in Polish with English summary). In: Geneza, litologia i stratygrafia utworów czwartorzędowych (ed. A. Kostrzewski). UAM, Poznań, Geografia, **57**: 137–154.

KEILHACK K. (1897) — Die Drumlinlandschaft in Norddeutschland. Jahrbuch der Königlichen Preußischen Geologischen Landesanstalt, **17**.

KEILHACK K. (1899) — Die Stillstandslagen des letzten Inlandeises und die hydrographische Entwicklung des Pommerschen Künstengebietes. Jahrbuch der Preußischen Geologischen Landesanstalt, **19**.

KEILHACK K. (1904) — Die grosse baltische Endmoräne und das Thorn — Eberswalder Haupttal. Eine Antwort an 6 Mass. Aschr. d. Deutsch. Geol. Gesel. Bd. **56**.

KLIEWE H. and KOZARSKI S. (1979) — Zur Verknüpfung von Marginalzonen im Bereich des Oderlobus. Acta Universitatis Nicolai Copernici. Geografia XIV, Nauki Matem.-Przyr., **46**: 21–30

KONDRACKI J. (1968) — Fizycznogeograficzna regionalizacja Polski i krajów sąsiednich w systemie dziesiętnym. Prace Geograf. IG i PZ PAN, **69**: 13–42

KONDRACKI J. (2000) — Geografia regionalna Polski. Wyd. Nauk. PWN, Warszawa.

KOPCZYŃSKA-ŻANDARSKA K. (1970) — The origin of relief of the Quaternary substratum in north-western Pomerania (in Polish with English summary). Stud. Geol. Pol., **33**

KURZAWA M. (1999) — Differentiation of Pleistocene cover over selected salt tectonics forms in NW Poland (in Polish with English summary). Prz. Geol. **47** (5): 489–498.

KURZAWA M. (2000) — Spatial construction model of Cenozoic cover in NW Poland presented on digital geologic maps of horizontal cutting (NW Poland) (in Polish with English summary). Prz. Geol., **48** (4): 306–312.

KURZAWA M. (2001) — Traces of vertical tectonic movements in Pleistocene sediments in NW Poland. Zeitschrift Geol. Wiss., **29** (1/2): 75–82.

LIEDTKE H. and J. MARCINEK (1994) — Physische Geographie Deutschlands. Justus Perthes Verlag Gotha.

LIEDTKE H. (1981) — Die nordischen Vereisungen in Mitteleuropa. Forschungen zur deutschen Landeskunde, **204**.

LÜTTIG G. (1991) — Erratic boulder statistics as a stratigraphic aid — Examples from Schleswig-Holstein. Newsletter Stratigr., **25** (2): 61–74

LÜTTIG G. (1999) — Geschiebestatistische Anmerkungen zur Quartärstratigraphie des nordischen Vereisungsgebietes. Eiszeitalter u. Gegenwart **49**: 144–163

MASŁOWSKA M. (1999) — Lithological characteristic of boulder clay of the north-western Poland (in Polish with English summary). Prz. Geol., **47** (10): 920–926.

MASŁOWSKA M. and MICHAŁOWSKA M. (1994) — Badania litologiczno-petrograficzne osadów czwartorzędowych dla Szczegółowej mapy geologicznej Polski w skali 1:50 000, ark. Dębno. Arch. OGM PIG

MASŁOWSKA M. and MICHAŁOWSKA M. (1995) — Badania litologiczne osadów czwartorzędowych, ark. Trzcińsko Zdrój. Sopot, Arch. Państ. Inst. Geol., Szczecin.

MEYER K-D. (2000) — Geschiebekundlich-stratigraphische Untersuchungen im Hannoverschen Wendland (Niedersachsen). Brandenburgische Geowissenschaftliche Beiträge, **7** (1/2): 115–125

MOJSKI E. J. (1968) — Zarys stratygrafii zlodowacenia północnopolskiego (bałtyckiego) w północnej i środkowej części Polski. Prace Geogr. IG PAN: 37–5774.

MÜNNICH G. (1932) — Quantitative Geschiebeforschung in Rügen und Vorpommern. Zeitschr. f. Geschiebeforschung, **8**: 59–61.

PIOTROWSKI A. (1990*a*) — Szczegółowa mapa geologiczna Polski 1:50 000, ark. Cedynia (in Polish). Państ. Inst. Geol., Warszawa.

PIOTROWSKI A. (1990*b*) — Szczegółowa mapa geologiczna Polski 1:50 000, ark. Chojna (in Polish). Państ. Inst. Geol., Warszawa.

PIOTROWSKI A. (1991*a*) — Objaśnienia do Szczegółowej mapy geologicznej Polski 1:50 000, ark. Cedynia. Państ. Inst. Geol., Warszawa.

PIOTROWSKI A. (1991*b*) — Objaśnienia do Szczegółowej mapy geologicznej Polski 1:50 000, ark. Chojna. Państ. Inst. Geol. Warszawa.

PIOTROWSKI A. (1996) — Szczegółowa mapa geologiczna Polski 1:50 000, ark. Trzcińsko Zdrój (345). Państ. Inst. Geol. Warszawa.

PIOTROWSKI A. (1999) — Objaśnienia do Szczegółowej mapy geologicznej Polski 1:50 000, ark. Stara Rudnica (383) i Mieszkowice (384). Państ. Inst. Geol., Warszawa.

RUTKOWSKI J. (1999) — Badania petrograficzne żwirów pochodzenia lodowcowego z rejonu Suwałk. In: Dynamika procesów stokowych i fluwialnych w rzeźbie młodoglacjalnej z rejonu Suwałk (eds. P. Szwarczewski and E. Smolska): 53–55. Univ. Warsaw.

RUTKOWSKI J. (2003) — Introduction to the petrographic study of gravels (in Polish with English summary). In: Analizy sedymentologiczne osadów glacigenicznych (eds. M. Harasimiuk and S. Terpiłowski): 13–21. Wyd. UMCS, Lublin.

RUTKOWSKI J. (2006) — Badania petrograficzne żwirów. In: Badania cech teksturalnych osadów czwartorzędowych i wybrane metody oznaczania ich wieku (eds. E. Mycielska-Dowgiałło and J. Rutkowski). Univ. Warsaw (in print).

RÜHBERG N. (1987) — Die Grundmoräne des jüngsten Weichselvorstoßes im Gebiet der DDR. Zeitschr. Geol. Wiss., **15** (6): 759–767.

RÜHBERG N. (1999) — Über den Wert der Kleingeschiebezählungen (KGZ). Geschiebekunde aktuell, **15** (3): 87–100.

SCHULZ W. (1961) — Sedimentpetrographische Untersuchungen im Pleistozän westlich von Halle (Saale). Geologie, **10** (1): 30–49.

SCHULZ W. (1964) — Die Findlinge Mecklenburgs als Naturdenkmäler. Arch. F. Naturschutz, **4** (3): 99–130.

SCHULZ W. (1968) — Die Verbreitung großer Geschiebe im Bereich der DDR. Archiv f. Naturschutz u. Landschaftsforschung, **8** (3): 211–229

SMED P. (2002) — Steine aus dem Norden. Geschiebe als Zeugen der Eiszeit in Norddeutschland. Gebrüder Borntraeger. Berlin, Stuttgart.

WIŚNIEWSKI E. (1971) — Struktura i tekstura sandru ostródzkiego oraz teras doliny górnej Drwęcy. Prace Geogr., **83**: 1–95.

ZABIELSKI R. (2000) — Petrographical composition of tills near Konin with application statistic analysis (Central Poland). Prz. Geol., **48** (4): 345–350.

ZABIELSKI R. (2004) — Which petrographical features gravel fromm tills can be useful for lithostratigraphy (in Polish with English summary). Prz. Geol., **52** (4): 340–346.

APPENDIX A

Study sites of the regions A, B, C

Region		Study sites		
A		1. Krassow 2. Büschow 3. Perniek 4. Pinnowhof 5. Passee 6. Tützen 7. Mankmoos 8. Qualitz	9. Krakow am See 10. Zietlitz 11. Blücherhof 12. Langhagen 13. Hallalit 14. Jabel 15. Kargow 16. Klein Flotow	17. Rethwisch 18. Sophienhof 19. Adamsdorf 20. Warlin 21. Kreuzbruchhof 22. Koldenhof
B	B1	23. Buchholz 24. Milmersdor	25. Götschendorf 26. Althüttendorf	27. Stolzenhagen
	B2	28. Golice 29. St. Objezierze 30. Łaziszcze 31. Mętno	32. Chełm Górny 33. Chojna 34. Małe Stoki 35. Czartoria	36. Trzcińsko Zdrój 37. Nawodna 38. Strzelczyn
	B3	39. Płomień 40. Chrapowo 41. Krzęcin 42. Pławno 43. Rakowo 44. Korytowo 45. Rzecko	46. Pomień wies 47. Rajsko 48. Podgórzyn 49. Nętkowo 50. Żółwino 51. Strzebielewo 52. Radziszewo	53. Krąpiel 54. Trąbki 55. Wieleń Pomorski 56. Ińsko 57. Storkowo Ińskie 1 58. Storkowo Ińskie 2
C		59. Wiewiecko 60. Woliczno 61. Kalisz Pomorski 62. Mirosławiec 63. Osiek Dr. 64. Bobrowo	65. Miłkowo 66. Lipowa Góra 67. Prosinko 68. Chlebowo 69. Dobrosław 70. Ostrowąs	71. Kołacz 72. Kluczewo 73. Czarne Wlk. 74. Rakowo 75. Lędyczek

APPENDIX B

Basic statistical parameters of the petrographic groups and coefficients of fluvioglacial deposits of region A

A/N=29	Mean	Perc. bound.		Min.	Max.	Stand. dev.
		–95%	95%			
Kr	40.78	39.13	42.44	33.43	53.76	4.34
Wp1	29.63	28.00	31.26	18.36	37.87	4.30
Wp2	1.96	1.64	2.28	0.52	4.17	0.84
Wk	0.13	0.03	0.23	0.00	0.90	0.26
D	0.01	0.00	0.04	0.00	0.35	0.06
Pp	15.07	13.84	16.29	8.58	21.52	3.22
Łp	3.62	2.68	4.57	0.81	9.94	2.49
Krz	5.44	4.39	6.49	0.19	10.54	2.76
Q	2.71	1.71	3.71	0.24	10.41	2.63
Qml	0.16	0.08	0.25	0.00	0.81	0.23
O/Kr	1.26	1.16	1.36	0.71	1.72	0.26
Kr/W	1.33	1.20	1.47	0.89	2.66	0.37
A/B	1.06	0.96	1.16	0.58	1.59	0.26
Krz/Kr	0.14	0.11	0.16	0.00	0.26	0.07
Q/Kr	0.06	0.04	0.09	0.01	0.23	0.06

Perc. bound. — percentile boundaries, Stand. dev. — standard deviation; symbols of petrographic groups and coefficients explained in the text

APPENDIX C

Basic statistical parameters of the petrographic groups and coefficients of fluvioglacial deposits of subregion B1

B1/N=9	Mean	Perc. bound.		Min.	Max.	Stand. dev.
		–95%	95%			
Kr	41.52	37.51	45.53	35.13	50.44	5.22
Wp1	31.28	24.77	37.78	15.29	44.80	8.47
Wp2	1.95	1.18	2.72	0.54	3.72	1.00
Wk	0.04	0.00	0.13	0.00	0.35	0.12
D	0.00	–	–	0.00	0.00	0.00
Pp	15.38	11.29	19.48	6.32	25.21	5.33
Łp	4.75	2.45	7.06	0.28	10.37	3.00
Krz	1.64	0.55	2.73	0.35	4.36	1.42
Q	2.66	1.83	3.49	1.27	4.54	1.08
Qml	0.26	0.04	0.49	0.00	0.88	0.30
O/Kr	1.32	1.09	1.55	0.86	1.66	0.29
Kr/W	1.38	0.91	1.85	0.80	2.79	0.61
A/B	1.19	0.98	1.40	0.73	1.51	0.27
Krz/Kr	0.04	0.01	0.07	0.01	0.10	0.03
Q/Kr	0.06	0.05	0.08	0.03	0.09	0.02

APPENDIX D

Basic statistical parameters of the petrographic groups and coefficients of fluvioglacial deposits of subregion B2

B2/N=23	Mean	Perc. bound.		Min.	Max.	Stand. dev.
		–95%	95%			
Kr	37.07	34.22	39.92	24.68	52.23	6.60
Wp1	36.82	34.39	39.26	26.50	49.80	5.62
Wp2	2.27	2.01	2.53	1.29	3.60	0.60
Wk	0.03	0.00	0.09	0.00	0.58	0.12
D	0.02	0.00	0.05	0.00	0.41	0.08
Pp	15.17	13.70	16.65	7.84	20.44	3.41
Łp	4.40	3.04	5.77	0.36	11.07	3.17
Krz	0.58	0.33	0.84	0.00	2.39	0.59
Q	2.02	1.67	2.36	0.56	3.46	0.80
Qml	0.34	0.22	0.45	0.00	0.97	0.27
O/Kr	1.66	1.46	1.85	0.83	2.76	0.45
Kr/W	0.98	0.85	1.11	0.61	1.77	0.30
A/B	1.53	1.36	1.70	0.78	2.44	0.40
Krz/Kr	0.02	0.01	0.02	0.00	0.06	0.01
Q/Kr	0.06	0.05	0.07	0.01	0.11	0.03

APPENDIX E

Basic statistical parameters of the petrographic groups and coefficients of fluvioglacial deposits of subregion B3

B3/N=48	Mean	Perc. bound.		Min.	Max.	Stand. dev.
		–95%	95%			
Kr	36.64	34.63	38.65	16.06	52.20	6.92
Wp1	37.97	35.80	40.14	14.52	53.59	7.46
Wp2	2.00	1.79	2.20	0.59	4.72	0.70
Wk	0.10	0.00	0.21	0.00	2.52	0.37
D	0.03	0.00	0.07	0.00	0.93	0.14
Pp	15.20	14.13	16.27	8.27	23.75	3.68
Łp	3.52	2.63	4.41	0.17	11.28	3.05
Krz	0.51	0.33	0.70	0.00	3.31	0.64
Q	2.85	2.45	3.24	0.31	6.77	1.36
Qml	0.40	0.28	0.52	0.00	1.84	0.43
O/Kr	1.73	1.52	1.93	0.88	4.92	0.69
Kr/W	0.99	0.86	1.13	0.30	3.46	0.47
A/B	1.56	1.39	1.74	0.86	3.87	0.59
Krz/Kr	0.01	0.01	0.02	0.00	0.08	0.02
Q/Kr	0.08	0.07	0.09	0.01	0.22	0.04

APPENDIX F

Basic statistical parameters of the petrographic groups and coefficients of fluvioglacial deposits of region C

C/N=49	Mean	Perc. bound.		Min.	Max.	Stand. dev.
		-95%	95%			
Kr	43.65	40.58	46.73	31.00	79.57	10.70
Wp1	31.42	28.62	34.23	9.33	48.00	9.78
Wp2	1.78	1.50	2.06	0.00	4.00	0.97
Wk	0.01	0.00	0.03	0.00	0.25	0.05
D	0.00	–	–	0.00	0.00	0.00
Pp	14.61	13.37	15.85	7.45	27.00	4.30
Łp	3.68	2.37	4.98	0.00	25.00	4.54
Krz	0.17	0.06	0.28	0.00	1.94	0.39
Q	3.88	3.14	4.62	0.00	10.55	2.58
Qml	0.37	0.22	0.52	0.00	3.00	0.53
O/Kr	1.29	1.15	1.44	0.25	2.11	0.50
Kr/W	1.66	1.27	2.06	0.66	7.57	1.37
A/B	1.18	1.04	1.32	0.25	1.99	0.48
Krz/Kr	0.00	0.00	0.01	0.00	0.04	0.01
Q/Kr	0.09	0.07	0.10	0.00	0.21	0.05

APPENDIX G

Results of the *U*-test for the petrographic groups and coefficients of 4–10 mm fluvioglacial gravel of the Odra lobe (B) and the adjacent regions (A, C) of the last glaciation Pomeranian phase

U-Test	sum of ranks		Z corr.	p corr.	sum of ranks		Z corr.	p corr.	sum of ranks		Z corr.	p corr.
variable	A/N=29	B/N=80			B/N=80	C/N=49			A/N=29	C/N=49		
Kr	1956	4039	2.475	**0.013**	4530	3855	–3.251	**0.001**	1084	1997	–0.636	0.525
Wp1	855	5140	–5.074	**<0.001**	5825	2560	3.033	**0.002**	956	2125	–1.959	**0.050**
Wp2	1464	4531	–0.898	0.369	5528	2857	1.592	0.111	1210	1871	0.667	0.505
Wk	1767	4228	1.682	0.093	5401	2984	1.703	0.088	1323	1758	2.923	**0.003**
Dp	1577	4418	–0.340	0.733	5298	3087	1.584	0.113	1170	1911	1.300	0.194
Pp	1561.5	4433.5	–0.230	0.818	5480.5	2904.5	1.361	0.173	1233	1848	0.905	0.366
Łp	1604	4391	0.062	0.951	5499	2886	1.451	0.147	1245.5	1835.5	1.034	0.301
Krz	2644	3351	7.209	**<0.001**	6239.5	2145.5	5.218	**<0.001**	1837	1244	7.465	**<0.001**
Q	1356	4639	–1.639	0.101	4633	3752	–2.752	**0.006**	902	2179	–2.518	**0.012**
Qml	1176.5	4818.5	–2.928	**0.003**	5372	3013	0.853	0.394	1009.5	2071.5	–1.495	0.135
O/Kr	1056	4939	–3.696	**<0.001**	5859	2526	3.198	**0.001**	1113	1968	–0.336	0.737
Kr/W	2235	3760	4.389	**<0.001**	4475	3910	–3.518	**<0.001**	1204.5	1876.5	0.610	0.542
A/B	923	5072	–4.608	**<0.001**	5846	2539	3.135	**0.002**	1038	2043	–1.111	0.266
Krz/Kr	2638	3357	7.168	**<0.001**	6130	2255	4.619	**<0.001**	1835	1246	7.299	**<0.001**
Q/Kr	1251.5	4743.5	–2.355	**0.019**	4790.5	3594.5	–1.987	**0.047**	874	2207	–2.807	**0.005**

N — number of observations; Z corr. — value of the corrected test according to tied ranks for the quantity above 20; p corr. — significant level counted for Z corr.; significant values are bolded

APPENDIX H

Results of the *U*-test for the petrographic groups and coefficients of 4–10 mm fluvioglacial gravel of the Odra lobe

U-Test	sum of ranks		Z corr.	p corr.	sum of ranks		Z corr.	p corr.	sum of ranks		Z corr.	p corr.
variable	B1/N=9	B2/N=23			B2/N=23	B3/N=48			B1/N=9	B3/N=48		
Kr	194	334	1.907	0.057	817	1739	–0.135	0.892	341	1312	1.751	0.080
Wp1	104	424	–1.865	0.062	749	1807	–0.971	0.332	155	1498	–2.320	**0.020**
Wp2	122	406	–1.111	0.267	974	1582	1.794	0.073	250	1403	–0.241	0.810
Wk	151	377	0.207	0.836	762	1794	–1.242	0.214	242	1411	–0.604	0.546
Dp	144	384	–0.626	0.532	818	1738	–0.307	0.758	247.5	1405.5	–0.763	0.445
Pp	151	377	0.105	0.917	833	1723	0.061	0.951	275	1378	0.306	0.759
Łp	162	366	0.566	0.572	947	1609	1.462	0.144	320	1333	1.291	0.197
Krz	200	328	2.162	**0.031**	906.5	1649.5	0.972	0.331	397	1256	2.994	**0.003**
Q	178	350	1.236	0.216	645	1911	–2.249	**0.025**	257	1396	–0.088	0.930
Qml	129	399	–0.826	0.409	821.5	1734.5	–0.081	0.936	226.5	1426.5	–0.763	0.445
O/Kr	98	430	–2.117	**0.034**	851	1705	0.283	0.777	186	1467	–1.641	0.101
Kr/W	201	327	2.200	**0.028**	864	1692	0.442	0.658	367	1286	2.320	**0.020**
A/B	93	435	–2.326	**0.020**	855	1701	0.332	0.740	187	1466	–1.619	0.105
Krz/Kr	197	331	2.037	**0.042**	898	1658	0.867	0.386	388	1265	2.796	**0.005**
Q/Kr	169.5	358.5	0.880	0.379	613.5	1942.5	–2.636	**0.008**	202	1451	–1.291	0.197