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Attempt of lithostratigraphic correlation of tills in northeastern Poland and southern Lithuania

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Six boreholes have been completed in the Polish–Lithuanian borderland. Samples of tills were collected to petrographic analysis of gravels 5–10 mm in diameter. Petrographic characteristics of tills were compared with lithotypes from central part of the Mazury Lakeland and the Augustów Lowland. Stratigraphic position of tills has been defined and then, the results were recalculated with application of the Lithuanian petrographic method. Comparative study indicated that there is no stratigraphic correlation between tills in southern Lithuania and northeastern Poland.

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Key words: Polish–Lithuanian borderland, Pleistocene, tills, lithostratigraphy.

INTRODUCTION

Similar methods of evaluation of diagnostic features of tills have been applied for years, both in Poland and Lithuania. These features are fundamental for lithostratigraphic correlation of Pleistocene sediments. Methods are similar, being based on the same substantial assumptions (A. I. Gaigalas, 1979; J. Rzechowski, 1971). Since a quantitative evaluation of petrographic components, leading in lithostratigraphic correlation, is different in both countries, no direct stratigraphic correlation could be made between geological profiles in Poland and Lithuania so far. As an entirely uniform research method could not be developed previously, this paper presents a comparison of both methods. An attempt is also made to draw stratigraphic conclusions based on lithostratigraphic correlations of tills in the Polish–Lithuanian borderland. This study is a result of cooperation between the Polish Geological Institute in Warsaw with the Lithuanian Geological Institute in Vilnius and with Professor Dr. A. I. Gaigalas (Vilnius University).

METHODS

A standard lithologic-petrographic study of Pleistocene sediments collected from drilling cores has been continued in Poland for years for needs of the *Detailed Geological Map of Poland* in scale of 1:50 000 (J. Rzechowski, 1971, 1974). Such a study comprises the analyses of grain size, petrography of gravels in tills, heavy minerals, roundness of quartz grains in sands, and content of carbonates. Some other determinations are occasionally done: pH, chemical composition, content of microelements and feldspars. Petrographic composition of gravels (5–10 mm in diameter) in tills was found the most applicable to lithostratigraphy of the Pleistocene. It was revealed by J. Rzechowski (see Table 1) and the author (S. Lisicki, 1996*a*, *b*, 1997).

A. I. Gaigalas (1979) presented a method which is applied to lithologic-petrographic study in Lithuania. It comprises orientation of gravels in tills (in outcrops), grain size and petrographic analysis of gravels from tills (3–5, 5–7, 7–10 and 10–30 mm in diameter), composition of heavy minerals (frac-

Table 1

Application of analysis to determination of sediment features (after J. Rzechowski, unpubl. data)

Analysis	Origin — sedimentary environment	Facies	Lithostratigraphy	Regional lithologic type	Source area	Hypergenesis
Grain size	++	++	+	+++	++	++
Petrography of gravels	++	?	+++	++	+++	++
Heavy minerals	++	++	++	++	+++	++
Roundness of quartz grains	+++	++	+	++	+	+
Content carbonates	++	+	+	++	+	+++

+++ — very distinct determination, ++ — common determination, + — local determination e.g. in single sections, ? — no systematic examination

tion 0.25–0.1 mm), petrography of key Scandinavian eratics (fraction > 0.5 cm) and geochemical composition. Analysis of petrographic composition of gravels (5–10 mm in diameter) from tills is the most applicable for samples from boreholes. It is well suitable to lithostratigraphy of tills and if accompanied by petrographic analysis of key Scandinavian eratics allows, according to A. I. Gaigalas, to construct a stratigraphic scheme of the Pleistocene in Lithuania.

PETROGRAPHIC ANALYSIS

In Poland, petrographic analysis of gravels (5–10 mm in diameter, 100 grains in a sample) from tills (J. Rzechowski, 1971, 1974) gives contents of different groups of Scandinavian rocks (northern — the Palaeozoic and older rocks, as well as the Jurassic and Triassic ones which are very rare in Poland) i.e. crystalline rocks (Kr), limestones (Wp), dolomites (Dp), sandstones and quartzites (Pp), quartz (Qp), and the rocks of local origin (Tertiary and Cretaceous ones) i.e. limestones and marls (W_L), sandstones (P_L), siltstones and claystones (M_L). Then, petrographic coefficients O/K-K/W-A/B are calculated. They are composed of three coefficients (O/K, K/W and A/B) that present relations between different Scandinavian rock groups in tills, where: O — total of sedimentary rocks (Wp + Dp + Pp + northern shales), K — total of crystalline rocks and northern quartz (Kr + Qp), W — total of carbonate rocks (Wp + Dp), A — total of rocks non-resistant to destruction (Wp + Dp + northern shales), B — total of resistant rocks (Kr + Qp + Pp). Some publications on lithologic-petrographic examination of tills in Poland introduce also a factor Dp/Wp, being ratio of northern dolomites to northern limestones and of special significance in the Suwałki region (J. A. Czerwonka, D. Krzyszkowski, 1995).

Petrographic analysis of gravels (5–10 mm in diameter, about 300 grains in a sample) from tills, as applied in Lithuania, includes the following rocks (A. I. Gaigalas, 1979):

— crystalline rocks, northern quartz, feldspars, and subordinately quartzites (equivalent roughly in the Polish method to a total of crystalline rocks and northern quartz i.e. Kr + Qp),

— Jothnian, Palaeozoic and Mesozoic sandstones and occasional siltstones (equivalent in the Polish method to northern sandstones Pp),

— mostly Devonian dolomites (equivalent in the Polish method to northern dolomites Dp),

— two groups of limestones: the first group of organogenic ones of the Ordovician and Silurian, and the other group of the Palaeozoic, Triassic and Jurassic (a total of northern limestones Wp in the Polish method),

— predominant Cretaceous marls (in the Polish method roughly equal to the all local rocks — mostly Cretaceous and Palaeocene limestones and marls, difficult to separate from one another $W_L + P_L + M_L$).

In the Lithuanian publications, contents of the mentioned rocks is commonly presented with a use of bar graphs (A. I. Gaigalas, 1979). In the same way as in the Polish method, the 100% content of such bars is completed by other constituents like flints, lydites, phosphorites and others. A. I. Gaigalas (1979) presents results of petrographic analysis also with a use of histograms that indicate contents of gravels of different rocks in particular tills, in relation to average contents of these gravels as calculated for all the tills in many sections within the area.

The other coefficient K_0-V-K_2 is occasionally applied by the Lithuanian geologists to petrographic studies: K_0 defines ratio of dolomites to the Ordovician and Silurian limestones, V is a ratio of dolomites and of other sedimentary rocks, and K_2 is a ratio of crystalline rocks with quartz and quartzites to all sedimentary rocks. Furthermore, index S is occasionally calculated as ratio of dolomites to sandstones.

STUDY AREA

Geological material was collected from 6 boreholes located in the Polish–Lithuanian borderland near Wiżajny, Suwałki Lakeland (Fig. 1). Five boreholes on the Polish side were done for needs of the *Detailed Geological Map of Poland* in scale of 1:50 000, the sheets Żytkiejmy, Wiżajny and Poszeszupie. These boreholes are designated: Żytkiejmy Forestry Headquarters (Żytkiejmy F. H.), Żytkiejmy, Bolcie, Stankuny and Poszeszupie. The sixth borehole (Norvydai) was done on the Lithuanian side. Its profile was examined within the joint Polish–Lithuanian cooperation "The Yotwings belt — a fragment of Green Lungs of Europe". The Polish borderland has been already mapped in scale of 1:25 000, and the mentioned cooperation resulted in the *Geological Map of Northeastern Poland and Southern Lithuania* in scale of 1:200 000.

GEOLOGICAL RESEARCH

Geological material for lithologic-petrographic study was collected from five boreholes situated on the Polish side of the border (Z. Fert, 1987; Z. Fert, K. Pruszek, 1984). Samples from the borehole in Lithuania were examined at the Polish Geological Institute in Warsaw (K. Gronkowska-Krystek, S. Lisicki, 1996), and interpretation of results was done with reference to previous lithologic-petrographic studies, mainly of the central Mazury Lakeland (S. Lisicki, 1996*a*) and also of the Mrągowo Lakeland (S. Lisicki, 1996*b*, 1997) (Table 2), of the Augustów Lowland (J. A. Czerwonka, D. Krzyszkowski, 1995) and of the other areas (J. Rzechowski, 1974, 1977, 1986).

It was in 1995 when A. I. Gaigalas handed over to the Polish party a histogram, showing with average petrographic composition of gravels and its differences for particular tills (Fig. 2). The histogram presented results of the study in the Vištytis region in the Lithuanian–Russian borderland (Fig. 1). Quantitative data are presented too (Table 3). The same method was applied to the six boreholes (Table 4) and the results were presented (Fig. 3), together with the author's lithostratigraphic correlation of tills of the Wiżajny region (Table 5) and reference to the A. I. Gaigalas' correlation for the Vištytis region, against a stratigraphic scheme of the Pleistocene in Poland and Lithuania after J. Satkunas *et al.* (1996) (Table 5).

Fig. 1. Location of the study area and boreholes
Ż F. H. — Żytkiejmy Forestry Headquarters, Ż — Żytkiejmy, B — Bolcie, S — Stankuny, N — Norvydai, P — Poszeszupie; a — study area, b — reference area in the central Mazury Lakeland, c — study area in the Augustów Lowland

Lokalizacja obszaru badań i otworów wiertniczych
Ż F. H. — Żytkiejmy Nadleśnictwo, Ż — Żytkiejmy, B — Bolcie, S — Stankuny, N — Norvydai, P — Poszeszupie; a — obszar badań, b — porównywany obszar badań geologicznych centralnej części Pojezierza Mazurskiego, c — obszar cytowanych badań z Niziny Augustowskiej

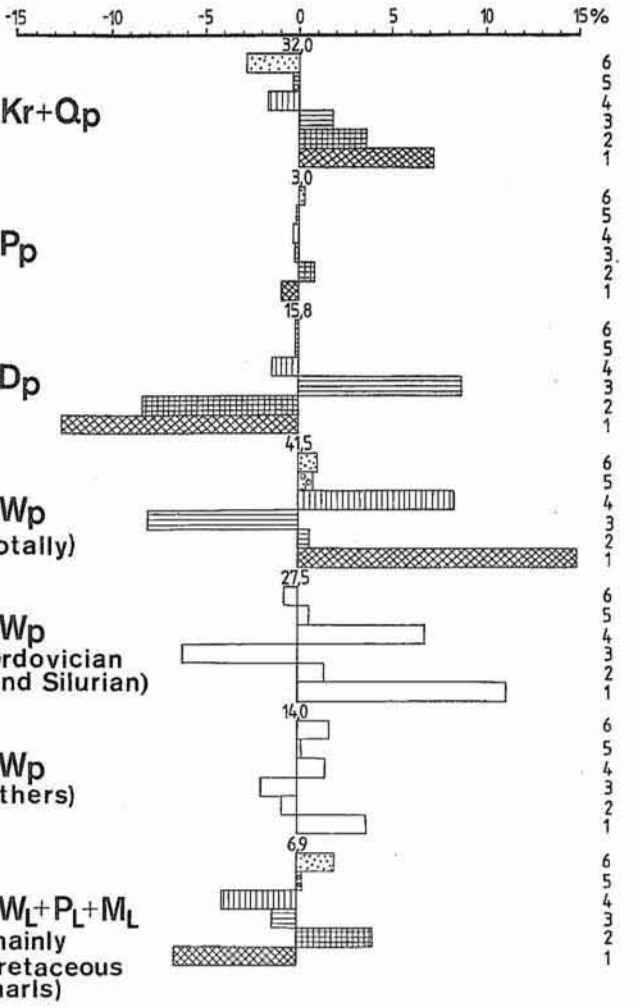


Fig. 2. Average petrographic composition of gravels for particular tills in the Vištytis region (Lithuanian–Russian borderland), after A. I. Gaigalas (pers. comm.)
Tills of the following glaciations: 1 — Dzukija, 2 — Dainava, 3 — Žemaitija, 4 — Medininkai; stadials of Nemunas Glaciation: 5 — Grūda, 6 — Baltija; see text for petrographic symbols

Uśredniony skład petrograficzny i różnice zawartości żwirów różnych rodzajów skał dla poszczególnych kompleksów glin zwałowych z rejonu Vištytis (pogranicze litewsko–rosyjskie) według A. I. Gaigalasa (inform. ustna)
Gliny zwałowe zlodowaceń: 1 — Dzukija, 2 — Dainava, 3 — Żemaitija, 4 — Medininkai; stadiały zlodowacenia Nemunas: 5 — Grūda, 6 — Baltija; symbole petrograficzne patrz tekst

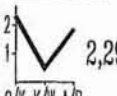
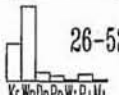
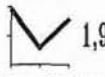
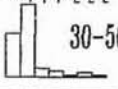
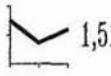
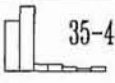
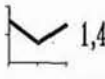
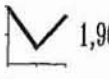
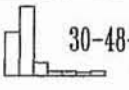
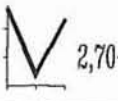
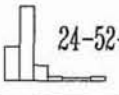
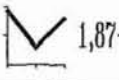
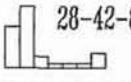
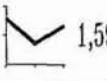
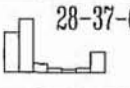
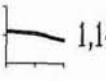
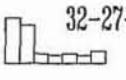
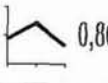
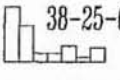
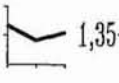
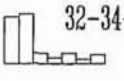
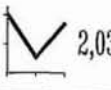
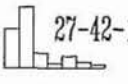
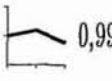
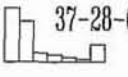
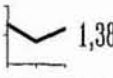
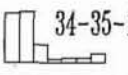
LITHOSTRATIGRAPHY OF TILLS

Tills in the examined borehole sections represent separate stadials and glaciations. Tills of the same stadials predominantly occur at the same altitude (Fig. 4). Sediments of eight glaciations were distinguished and their stratigraphic locations were defined according to a proposal by M. D. Baraniecka (1990). The constructed stratigraphic scheme has been already successfully applied for the central Mazury Lakeland (S. Lisicki, 1996*b*, 1997).

Till of the older stadial of the Narewian Glaciation was noted in three boreholes. It is 3–13 m thick, very stiff and grey or brown. It contains gravels of local rocks up to 23%, and the

Table 2

Average results of petrographic examination of gravels (5–10 mm in diameter) in tills from in 32 boreholes in the central Mazury Lakeland (after S. Lisicki, 1997)

Stratigraphy		Petrographical coefficients	Mean contents of gravels (%)	Number of boreholes with tills	
Glaciation	Stadial	O/K – K/W – A/B	Kr–Wp–Dp–Pp–W_L–P_L–M_L	with petrographical studies	without petrographical studies or weathered tills *
Vistulian–B	younger–B_2	 2,29–0,48–1,85	 26–52–6–4–1–5–1	13	5*
	older–B_1	 1,92–0,57–1,57	 30–50–6–4–1–3–1	17	–
Wartanian–W	younger–W_2	 1,51–0,74–1,20	 35–45–5–5–3–2–3	15	1
	older–W_1	 1,49–0,70–1,35	 35–48–5–2–1–2–1	8	–
Odranian–O	younger–O_2	 1,96–0,55–1,69	 30–48–9–3–3–2–3	17	–
	older–O_1	 2,70–0,40–2,34	 24–52–11–3–2–2–3	15	1
Liwiecian–C		 1,87–0,60–1,60	 28–42–8–3–3–3–10	21	–
Wilgian–G		 1,59–0,71–1,33	 28–37–6–3–2–3–14	19	–
Sanian–S	younger–S_2	 1,14–1,06–0,82	 32–27–7–6–7–6–9	14	1
	older–S_1	 0,86–1,41–0,64	 38–25–6–6–11–3–10	10	1
Nidanian–N	younger–N_2	 1,35–0,82–1,10	 32–34–7–4–7–3–6	16	1
	older–N_1	 2,03–0,54–1,71	 27–42–10–3–8–4–2	7	–
Narewian–A	younger–A_2	 0,99–1,18–0,76	 37–28–6–5–3–2–12	6	–
	older–A_1	 1,38–0,78–1,25	 34–35–12–2–3–3–6	5	–

* two horizons only; see text for explanations

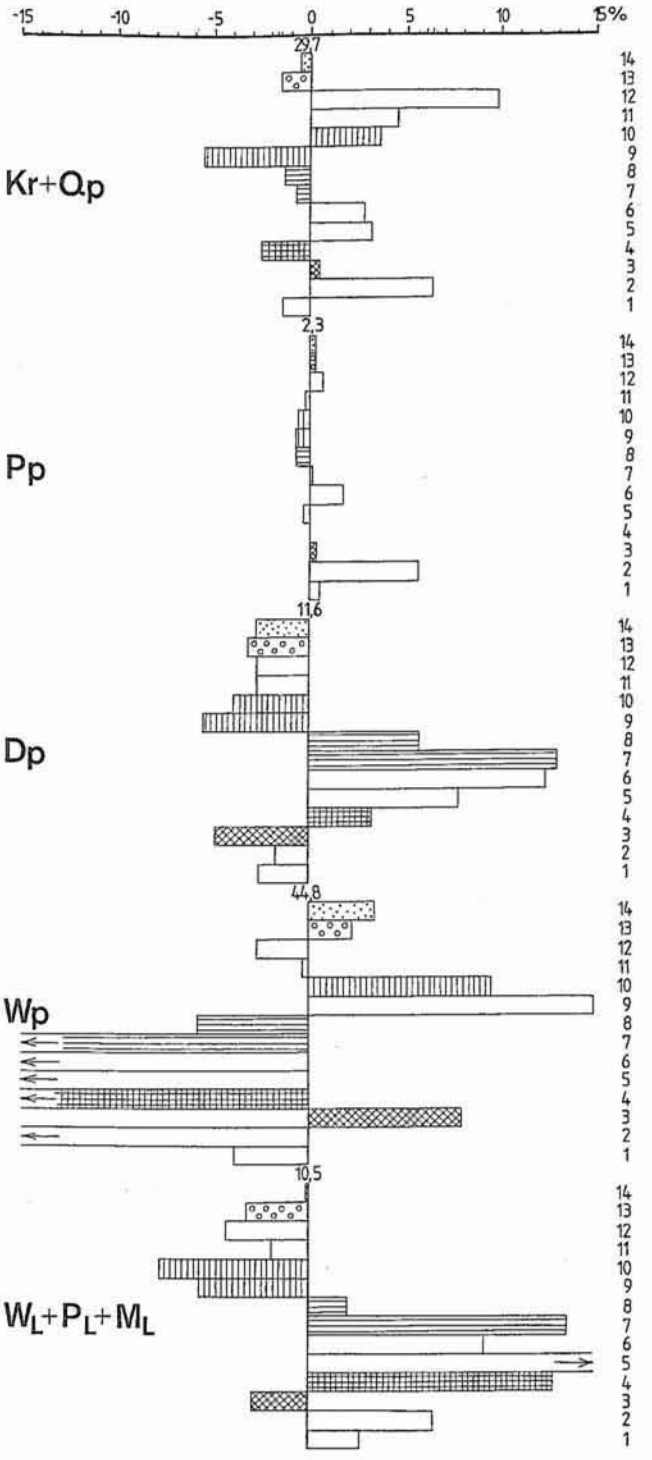


Fig. 3. Average petrographic composition of gravels for particular tills in the Wiżajny region (Polish–Lithuanian–Russian borderland)
Tills of the following glaciations: Narewian: 1 — A_1, 2 — A_2 in glacial rafts only; Nidanian: 3 — N_1 in glacial rafts only, 4 — N_2; Sanian: 5 — S_1, 6 — S_2; 7 — Wilgian G; 8 — Liwiecian C; Odranian: 9 — O_1, 10 — O_2; Wartanian: 11 — W_1, 12 — W_2; Vistulian: 13 — B_1, 14 — B_2; see text for petrographic symbols

Uśredniony skład petrograficzny i różnice zawartości żwirów różnych rodzajów skał dla poszczególnych poziomów glin zwałowych z rejonu Wiżajn (pogranicze polsko-litewsko-rosyjskie)
Gliny zwałowe zlodowaceń: narwi: 1 — A_1, 2 — A_2 tylko w formie porwaków; nidy: 3 — N_1 tylko w formie porwaków, 4 — N_2; sanu: 5 — S_1, 6 — S_2; 7 — wilgi G; 8 — liwca C; odry: 9 — O_1, 10 — O_2; warty: 11 — W_1, 12 — W_2; wisły: 13 — B_1, 14 — B_2; symbole petrograficzne patrz tekst

Table 3

Average content of gravels (5–10 mm in diameter) in tills from in boreholes in the Vištytis region (Lithuanian–Russian borderland)

Stratigraphy		Average contents of gravels [%]				
Glaciation	Stadial	Kr + Qp	Pp	Dp	Wp	$P_L + W_L + M_L$
		32.0	3.0	15.8	41.5	6.9
		differences in contents of gravels [%]				
Nemunas	Baltija	–2.8	0.3	–0.2	1.0	2.0
	Grūda	–0.3	–0.1	–0.2	–0.8	0.3
Medininkai		–1.6	–0.3	–1.4	8.3	–4.0
Žemaitija		1.8	–0.2	8.7	–8.0	–1.3
Dainava		3.6	0.8	–8.3	–0.6	4.0
Dzukija		7.2	–0.9	–12.6	14.8	–6.5

See text for petrographic symbols

mean petrographic coefficients are equal to from 1.45–0.72–1.35 at Żytkiejmy to 2.03–0.53–1.81 at Bolcie. Till of the younger stadial of the same glaciation seems to be present in the section at Norvydai, being there a thin glacial raft, embedded in a till of the younger stadial of the Sanian Glaciation. Petrographic coefficients of a single sample of this till are equal to 1.13–1.10–0.75 and dolomite content reaches approximately 10%.

Grey and grey-green till of the older stadial of the Nidanian Glaciation occurs as glacial rafts only, 9.5–15.0 m thick, embedded in a till of the Liwiecian Glaciation. Till of the older stadial has been encountered in three sections at Żytkiejmy F. H., Żytkiejmy and Stankuny (Fig. 4). Mean coefficients of this till range from 1.94–0.55–1.80 to 2.65–0.40–2.41, and a content of local rock gravels is poor (5–8%). Till of the younger stadial of the Nidanian Glaciation is thin, brown, and appears in two boreholes only: Żytkiejmy F. H. (1.28–0.82–1.15) and Żytkiejmy (1.25–0.82–1.19). Content of local rocks is distinctly high, particularly of local siltstones (M_L), reaching 36%.

Till of the Sanian Glaciation has been encountered in two sections only. At Żytkiejmy F. H., till of the older stadial is considerably reduced and its coefficients are equal to 0.87–1.19–0.82. At Norvydai, till of the younger stadial rests at altitude 25 m i.e. the lowest among the Pleistocene sediments in the study area. This till is 26 m thick, light grey and light brown. It contains abundant dolomites (D_p), and its mean petrographic coefficients are equal to 1.29–0.94–0.89.

Grey-brown till of the Wilgian Glaciation occurs in three sections. It is 4.0 to 9.6 m thick and its mean coefficients are between 1.25–0.82–1.19 and 1.69–0.64–1.50. Abundant chips of dolomites D_p (up to 25%) and local rocks (up to 31%), including local siltstones (up to 23%) are a characteristic feature.

The overlying red clayey complex is common. It is composed of red-brown clays and grey-brown lacustrine silts, containing fine gravels and brown clayey solifluction loams. Characteristic is the composition of gravels, with predomi-

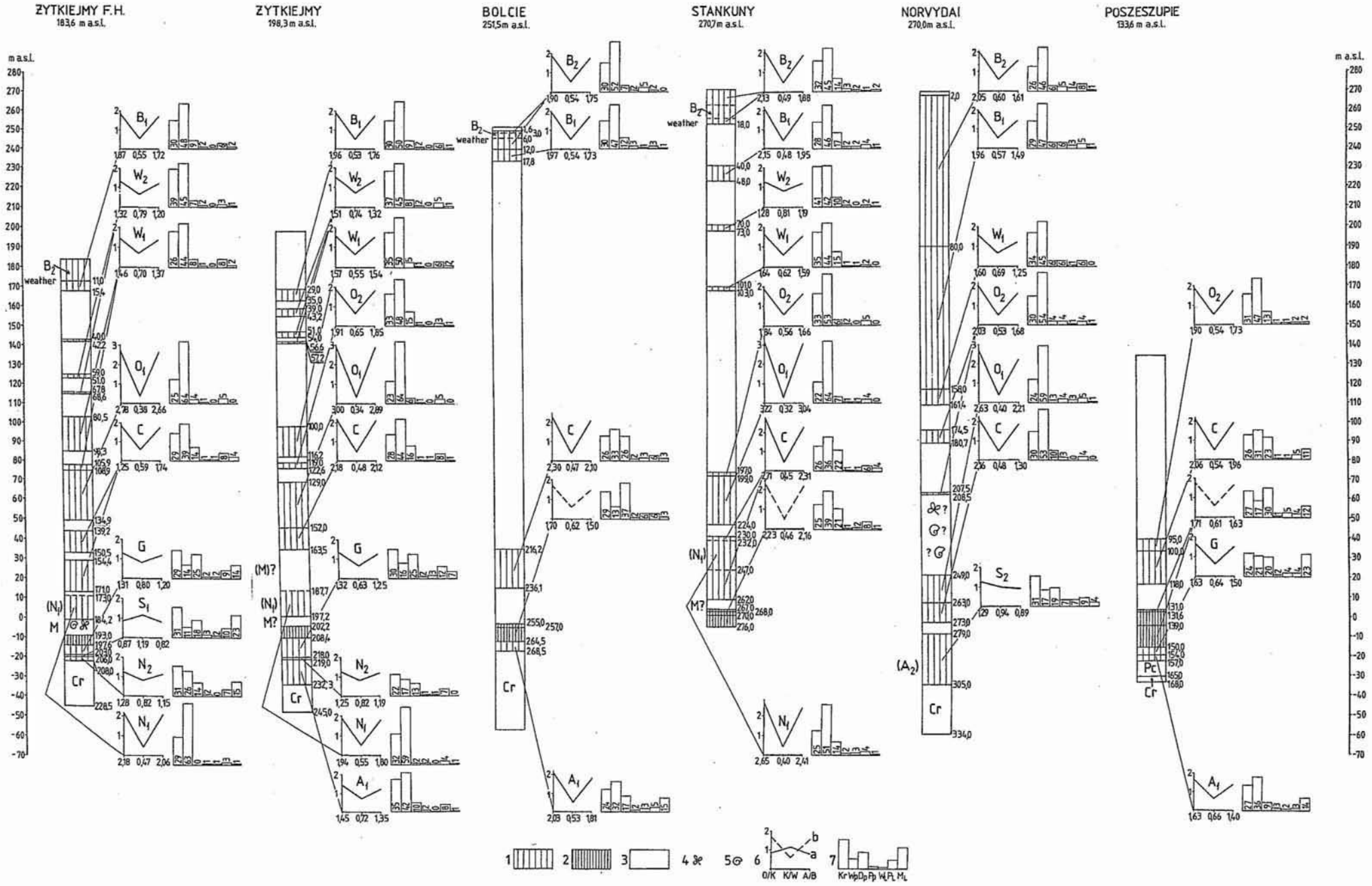

ŻYTKIEJMY F.H.
183,6 m a.s.l.
ŻYTKIEJMY
198,3 m a.s.l.
BOLCIE
251,5m a.s.l.
STANKUNY
270,7m a.s.l.
NORVYDAI
270,0m a.s.l.
POSZESZUPIE
133,6 m a.s.l.
m a.s.l.
B2
weather
B1
W2
W1
O2
O1
C
G
S2
S1
N2
N1
A1
(N1)
M
M?
(M)?
(A2)
Cr
Pc
1 2 3 4 5 6 7
O/K K/W A/B
Kr Wp Dp Fp W,P, ML

Table 4

Average content of gravels (5–10 mm in diameter) in tills from 6 boreholes in the Wiżajny region (Polish–Lithuanian–Russian borderland)

Stratigraphy		Average contents of gravels [%]				
		Kr + Qp 29.7	PP 2.3	Dp 11.6	Wp 44.8	PL + WL + ML 10.5
Glaciation	Stadial	differences in contents of gravels [%]				
Vistulian B	younger B_2	–0.5	0.3	–2.8	3.4	–0.1
	older B_1	–1.5	0.3	–3.2	2.2	–3.2
Wartanian W	younger W_2	9.8	0.7	–2.7	–2.7	–4.3
	older W_1	4.5	–0.2	–2.7	–0.3	–1.9
Odranian O	younger O_2	3.6	–0.6	–3.9	9.6	–7.8
	older O_1	–5.5	–0.7	–5.5	15.0	–5.7
Liwiecian C	jointly O_2+O_1	–4.0	–0.7	–5.2	14.2	–6.0
Wilgian G		–1.3	–0.7	5.7	–5.8	2.0
	jointly C+G	–0.7	0.1	13.0	–28.8	13.6
Sanian S	younger S_2	–1.2	–0.5	7.6	–11.6	4.9
	older S_1	2.8	1.7	11.6	–25.7	9.2
Nidanian N	younger N_2	3.2	–0.3	7.8	–35.8	24.2
	older N_1	–2.5	0.0	3.2	–25.1	12.8
Narewian A	younger A_2	(0.5)	(0.3)	(–4.9)	(8.0)	(–2.9)
	older A_1	(6.4)	(5.6)	(–1.7)	(–21.8)	(6.5)
		–1.4	0.5	–2.6	–3.9	2.7

See text for petrographic symbols; numbers in brackets are data for sediments in glacial rafts

nant dolomites D_p (21 to 37%). Sediments of the Mazovian Interglacial, probably of lacustrine origin, occur above the red clayey complex.

Till of the Liwiecian Glaciation is common. It is grey and occasionally grey-brown and together with a glacial raft of the older till of the Nidanian Glaciation in the section Stankuny reaches the greatest thickness of 32 m. Mean petrographic coefficients range from 1.85–0.59–1.74 to 2.71–0.45–2.31. Similarly as the till of the Wilgian Glaciation, this till contains also a considerable amount of dolomites Dp (up to 26%), and abundant local rocks (up to 17%) in most cases. Glacial rafts of till of the older stadial of the Nidanian Glaciation are common in a till of the Liwiecian Glaciation.

Characteristic for till of the older stadial of the Odranian Glaciation predominant gravels, composed of northern limestones (Wp) to 60%. Thus, respective mean petrographic coefficients are high, from 2.63–0.40–2.21 to 3.22–0.32–3.04 at poor content of local rocks (up to 9%). The till is grey, silty, and the thickest (25 m) in the section Stankuny. A till of younger stadial of the Odranian Glaciation is widespread. In general it is thin, brown, sandy or with sandy interbeddings. Its mean petrographic coefficients are from 1.84–0.56–1.66 to 2.03–0.53–1.68, and the local rocks are rare (3–6%).

Mostly thin, grey and brown tills of the Wartanian Glaciation are assigned to two stadials. Mean petrographic coefficients for a till of the older stadial are from 1.46–0.70–1.37 to 1.64–0.62–1.59 and are close to those of the younger stadial (1.28–0.81–1.19 to 1.51–0.74–1.32). There are local rock gravels (3–8%) in both tills.

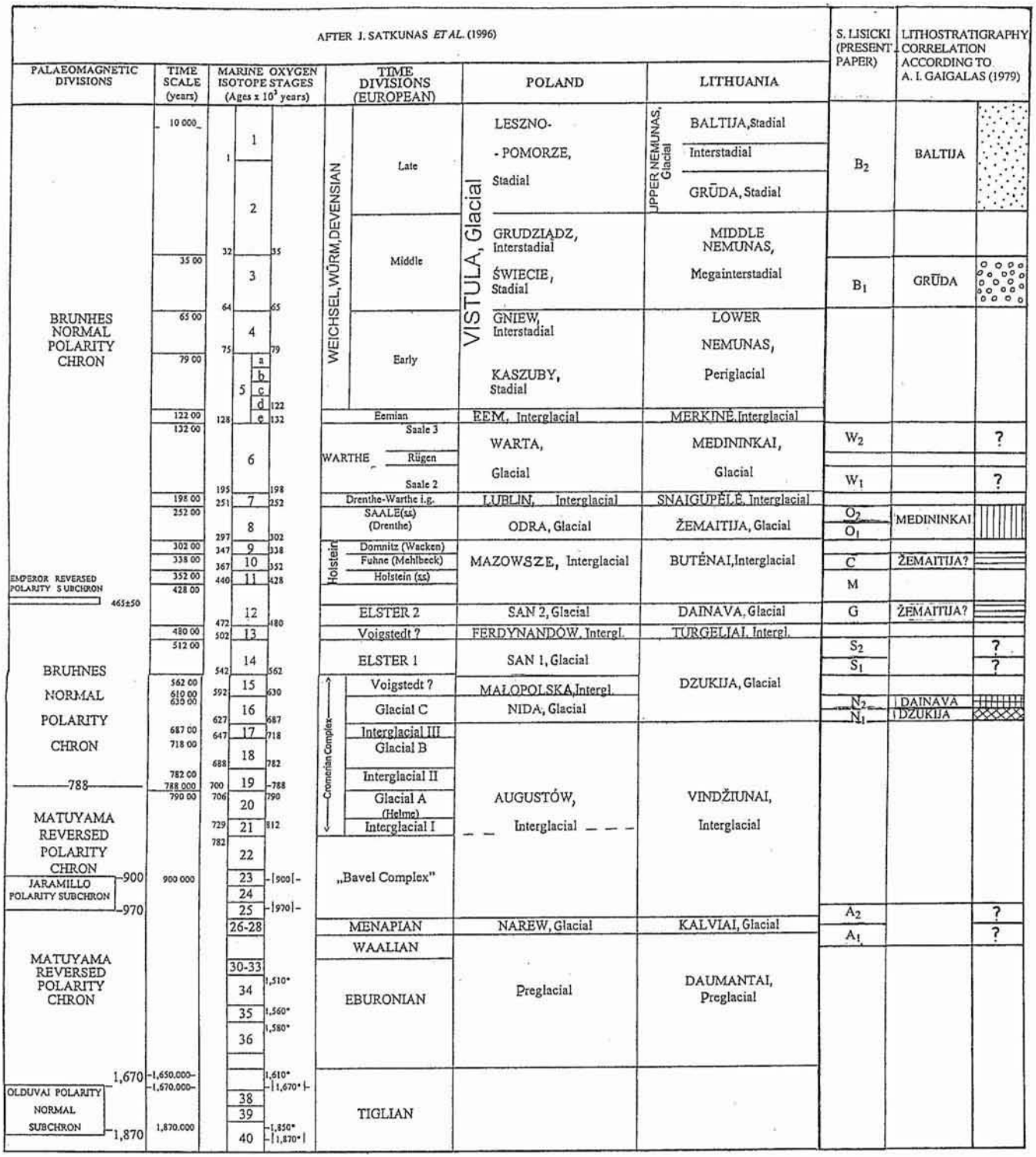
Distinct predominance of northern limestones (Wp) over other rocks is a characteristic feature of a till of the Vistulian Glaciation. In general, local rocks do not exceed 10%. Mean petrographic coefficients for tills of both stadials are close to each other, from 1.87–0.55–1.72 and 1.96–0.57–1.49 to 2.15–0.48–1.95 for the older stadial and from 1.90–0.54–1.75 to 2.13–0.49–1.88 for the younger stadial. Tills of the Vistulian

Fig. 4. Borehole sections with petrographic examination
1 — till, 2 — red clayey complex, 3 — other intramorainic sediments, 4 — fossil flora, 5 — fossil fauna, 6 — average petrographic coefficients for tills (a) and solifluction loams (b), 7 — average content (%) of gravels in tills and solifluction loams (detailed explanations in the text); stratigraphic symbols: Cr — *Cretaceous*; Pc — *Paleocene*; *Pleistocene*: M — *Mazovian Interglacial*; see Table 2 for the other explanations; stratigraphic symbols in brackets — glacial rafts

Profile otworów wiertniczych z wynikami badań petrograficznych
1 — glina zwałowa, 2 — osady czerwonego kompleksu ilastego, 3 — inne osady międzymorenowe, 4 — flora kopalna, 5 — fauna kopalna, 6 — średnie współczynniki petrograficzne glin zwałowych (a) i glin spływowych (b), 7 — średnie zawartości (%) żwirów w glinach zwałowych i glinach spływowych (szczegółowe objaśnienia patrz tekst); oznaczenia stratygraficzne: Cr — kreda; Pc — paleocen; plejstocen: M — interglacjał mazowiecki; pozostałe oznaczenia patrz tabela 2; symbole stratygraficzne w nawiasach — osady w formie porwaków

Table 5

Attempt of lithostratigraphic correlation of tills in the Wiżajny region (Polish–Lithuanian–Russian borderland), based on stratigraphic correlation of the Pleistocene in Poland and Lithuania after J. Satkunas *et al.* (1996)



Time scale, palaeomagnetic divisions, marine oxygen isotope stages after D. Q Bowen *et al.* (1986); for graphic explanations see Figure 2 and for stratigraphic symbols see Table 2

Glaciation are grey-brown with brown tint at the top, whereas tills of the younger stadial are strongly weathered. Thickness of tills of the youngest glaciation commonly does not exceed 18 m. Only in the section Norvydai, both tills are exceptionally thick (78 m each), reaching jointly 156 m.

Twelve *in situ* tills and discussed two types of tills in glacial rafts only are similar in their petrographic characteristics to fourteen tills noted in 32 boreholes in the central Mazury Lakeland (Table 2). All tills in the borderland and in the Mazury Lakeland belong to eight glaciations. In the latter area, tills are separated by lacustrine and fluvial sediments of the Mazovian Interglacial, age of which was defined by palynological examination of four sections (S. Lisicki, 1996*b*). Sediments of remaining six interglacials in the Mazury Lakeland were recognized on the basis of morphology and good roundness of quartz grains, predominance of garnets over amphiboles, good sorting, reconstruction of river valley patterns and location of these sediments with respect to well defined lithostratigraphy of tills.

Petrographic characteristics of the older till of the Narewian Glaciation is consistent with that of a till in the Augustów Lowland and designated T1B (J. A. Czerwonka, D. Krzyszkowski, 1995). This till occurs there under sediments of the Augustów Interglacial, i.e. the oldest interglacial investigated by palynologic analysis (Table 5).

Tills of stadials of the Nidanian Glaciation in northeastern Poland are also close to each other in their petrography. In the borderland, the older till occurs only in glacial rafts, embedded in a lower part or in a till of the Liwiecian Glaciation. The older till of the Nidanian Glaciation is petrographically similar to the till designated T4 in the Augustów Lowland, which — in the author opinion — occurs in a secondary deposit, and to the tills designated T2A and T3A, both *in situ* in the same area. A younger till of the Nidanian Glaciation corresponds to the first (oldest) lithotype of till P_1 of the South-Polish Glaciation (J. Rzechowski, 1974, 1977, 1986).

Occurrence of tills of the Sanian Glaciation is scarce in the Suwałki Lakeland. In comparison with tills of the same glaciation in the Mazury Lakeland, they contain more dolomites (Dp). Mean petrographic coefficients for the older till are also characteristic for the second and third lithotypes of tills P_{2a} and P_{2b} of the South-Polish Glaciation (J. Rzechowski, 1974, 1977, 1986). Coefficients of a till of the younger stadial are characteristic for the youngest till P_3 of the South-Polish Glaciation (J. Rzechowski, 1974, 1977, 1986).

The overlying till of the Wilgian Glaciation in the Suwałki Lakeland (Fig. 4) area indicates more dolomites (Dp), similar content of crystalline rocks (Kr), which has not been observed in the Mazury Lakeland (Table 2). Index for this till is close to a lithotype of a coeval till in southern Mazowsze (J. Rzechowski, 1986) or tills T2B, T2D, and T3D in the Augustów Lowland (J. A. Czerwonka, D. Krzyszkowski, 1995). Assignment of several lithotypes of tills from the Augustów Lowland to a till lithotype in the Suwałki Lakeland is due to slightly different calculation (made by the author) of the mean petrographic coefficients for tills in the Augustów area. This is also due to separation of tills in glacial rafts. A till of the Wilgian Glaciation is covered with clayey-loamy sediments of the red clayey complex. Structure and genesis of this complex in the Mazury Lakeland have been already discussed by the author (S. Lisicki, 1996*b*, 1997). Solifluction loams of this complex in the Mazury area are characterized by increased content of dolomites (Dp) as compared with the underlying till of the Wilgian Glaciation (Table 2). Similar situation is noted in the borderland where dolomites (Dp) are predominant in a petrographic composition of gravels in a solifluction loam; this predominance consists in much higher dolomite content than in a till of the Wilgian Glaciation (Fig. 2). In the Augustów Lowland, loams of the red clayey complex indicate similar petrographic characteristics (J. A. Czerwonka, D. Krzyszkowski, 1995).

Lacustrine sediments with remnants of flora and mollusc shells, presumably of the Mazovian Interglacial, occur in the section Żytkiejmy F. H. at depth of 184.2–193.0 m. Sediments of the same age are also noted in other analyzed sections e.g. at Żytkiejmy (Fig. 4). The section at Norvydai contains silty sands with admixture of humus and plant fragments at depth 211–215 m, and individual fragments of shells below. O. Kondratiene (pers. comm.) found a pollen spectrum to have been a washout, probably of the Mazovian Interglacial (Butenai) but redeposited during the Odranian Glaciation.

Till of the Liwiecian Glaciation contains more dolomites (Dp), in comparison with a till of the same glaciation in the central Mazury Lakeland (Table 5). Its petrographic characteristics are also similar to those in tills, designated T5 and T3B in the Augustów Lowland (J. A. Czerwonka, D. Krzyszkowski, 1995). Petrographic features of tills of the Odranian, Wartanian, and Vistulian Glaciations are entirely consistent with characteristics of lithotypes of tills in the Mazury Lakeland and with their petrographic composition in the Augustów Lowland.

Basing on the author's comparative studies, a conclusion can be drawn that coeval glacial horizons are similar, in respect to their petrography, in entire northeastern Poland and the Mazowsze Plain.

LITHUANIAN METHOD: LITHOSTRATIGRAPHIC AND STRATIGRAPHIC CONCLUSIONS

Petrographic composition of gravels from tills by A. I. Gaigalas in the Vištytis region (Fig. 1) exhibits differences in contents of different rocks of six complexes of tills in relation to average content of gravels in all complexes and sections (Fig. 2).

A till of the Dzukija complex contains more crystalline rocks (Kr) and northern limestones (Wp), and decreased amount of northern dolomites (Wp) and Cretaceous marls. Tills of the Dainava complex have, first of all, a higher than average content of crystalline rocks (Kr) and Cretaceous marls, and decreased amount of northern dolomites (Dp). The latter reach maximum in tills of the Žemaitija complex. On the other hand, these tills contain a lowest quantity of northern limestones (Wp). There is distinctly increased content of limestones (Wp) in tills of the Medininkai complex and decreased of northern dolomites (Dp) and Cretaceous marls. A till of the Nemunas Glaciation, belonging to two youngest

complexes of Grūda and Baltija, indicate an increased content of Cretaceous marls and a decreased amount of crystalline rocks (Kr). All these relations are presented in Table 3.

There are slight or relatively essential differences in petrographic characteristics in respective and presumably coeval tills in six Lithuanian regions, distinguished by A. I. Gaigalas (1979). Differences in petrographic composition of gravels can be explained by a different directions of advancing coeval glacier lobes, different distances between distinguished regions and bedrock outcrops, and mosaic distribution of zones of intensive glacial erosion.

Using the Lithuanian method, average content of gravels in tills was calculated jointly for six analyzed boreholes and in every till. Samples with strongly weathered tills were neglected. Calculations were done to compare petrography of fourteen lithostratigraphic horizons distinguished by the author on the Polish side of the border, with six complexes presented by A. I. Gaigalas for southern Lithuania. When calculating contents of gravels in tills, some results were neglected due to their inconsistency with petrographic background, being a joint average content of gravels for each till in particular boreholes. Neglected results were interpreted as characteristic for glacial rafts of older tills, embedded in younger ones (S. Lisicki, 1996*b*, 1997) or for strongly weathered tills (Table 4). The same symbols (*cf.* Fig. 2) have been used to appoint the corresponding tills (Fig. 3).

The most probable lithostratigraphic correlation of tills in northwestern and southern Lithuania could be presented in Table 5. Tills of the Dzukija complex correspond to a till of the older stadial of the Nidanian Glaciation N_1. Tills of the Dainava complex correspond to a till of the younger stadial of the Nidanian Glaciation N_2. Tills of the Žemaitija complex with a characteristic maximum of dolomites (Dp) represent tills of the Wilgian G and the Liwiecian C Glaciations, and presumably also tills of the Sanian Glaciation S_1 and S_2. Tills of the Medininkai complex do not represent tills of the Wartanian Glaciation W_1 and W_2, but correspond to tills of the Odranian Glaciation O_1 and O_2. Tills of the Grūda complex are in fact of the older (Świecie) stadial of the Vistulian Glaciation B_1, and tills of the Baltija complex represent the younger (Leszno–Pomeranian) stadial of the same glaciation B_2. Lithuanian equivalents of the Narewian A_1 and A_2, Sanian S_1 and S_2, and Wartanian W_1 and W_2 Glaciations are lacking in the compilation (Table 5). In a scheme of A. I. Gaigalas (Table 5), there is no lithostratigraphic equivalent of tills of the Narewian Glaciation A_1 and A_2, recognized in the borderland area, probably due to a lack of this complex in the Vištytis region in southern Lithuania. Tills of the Sanian Glaciation S_1 and S_2, sporadically present in the Suwałki Lakeland, contain, however, slightly increased content of crystalline rocks (Kr), their petrography is similar to the one of tills of the Žemaitija complex. This similarity could make tills of the Sanian Glaciation S_1 and S_2 be included into a lithostratigraphic complex of Žemaitija, which corresponds presumably to tills of the Wilgian G and Liwiecian C Glaciations. Tills of the Wartanian Glaciation W_1 and W_2 are thin (several metres only) and predominantly occur within a thick sandy-gravelly complex that separates tills of the Odranian O_1 and O_2 and the Vistulian B_1 and B_2 Glaciations (Fig. 4). Poor development of tills of the Wartanian Glaciation W_1 and W_2 in the Polish-Lithuanian borderland resulted in their missing in petrographic and lithostratigraphic characteristics in Lithuania. The fact that the Lithuanian geologists have included this entire sandy-gravelly complex to the Vistulian (Nemunas) Glaciation seems groundless.

CONCLUSIONS

1. All lithostratigraphic complexes of the Pleistocene in the Vištytis region, distinguished by A. I. Gaigalas (Fig. 2), correspond to some lithostratigraphic horizons distinguished in the Wiżajny area (Fig. 3).

2. South Lithuanian lithostratigraphic complexes do not correspond to assigned lithostratigraphic horizons in Poland (Table 5).

3. The lithostratigraphic scheme by A. I. Gaigalas for southern Lithuania does not fit to the scheme of stages and stadials in Poland (Table 5). Complexes of Dainava, Žemaitija and Medininkai do not correspond to chronostratigraphic stages designated with the same names. Furthermore, the Žemaitija complex seems to be correlated with tills of the Liwiecian Glaciation C and/or the Wilgian Glaciation G, or even the Sanian Glaciation S_1 and S_2. In northeastern Poland, tills of the Wilgian and the Liwiecian Glaciations separate sediments of the Mazovian Interglacial M, defined by palynologic analysis. In southern Lithuania, no stratigraphic complexes were distinguished that could correspond to the Narewian A_1 and A_2, Sanian S_1 and S_2 and Wartanian W_1 and W_2 Glaciations.

4. It is supposed that stratigraphic position of tills in southern Lithuania seems to be at least controversial. This could also be indicated by the idea of A. I. Gaigalas when he presents different regional petrographic development of coeval glacial complexes in Lithuania. This idea is inconsistent with the outlined, rather uniform petrographic image of coeval tills in northeastern Poland. It seems likely that repeated spatial correlation of tills in Lithuania may result in more clear determination of their petrographic image, thus a more complete lithostratigraphic and stratigraphic conformability of Pleistocene sediments in Lithuania and northeastern Poland.

Translated by Zdzisław Siwek

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PRÓBA KORELACJI LITOSTRATYGRAFICZNEJ GLIN ZWAŁOWYCH POLSKI PÓŁNOCNO-WSCHODNIEJ I POŁUDNIOWEJ LITWY

Streszczenie

W Polsce i na Litwie stosuje się od lat podobną metodykę oceny cech diagnostycznych osadów morenowych będących podstawą korelacji litostratygraficznej plejstocenu. Dla potrzeb realizacji *Szczegółowej mapy geologicznej Polski* w skali 1:50 000 wykonuje się standardowe badania litologiczno-petrograficzne osadów plejstoceńskich, pobieranych z rdzeni wiertniczych. Metodyka takich badań została opracowana w Polsce przez J. Rzechowskiego (1971, 1974), a na Litwie przez A. I. Gaigalasa (1979). Najbardziej przydatnymi do określania litostratygrafii osadów morenowych, a tym samym dla konstrukcji schematów stratygraficznych plejstocenu, są wyniki analizy składu petrograficznego żwirów glin zwałowych.

Dla analizy składu petrograficznego żwirów (próbki zawierające min. 100 ziaren o średnicy 5–10 mm) z glin zwałowych, stosowanej w Polsce, oblicza się zawartość procentową różnych grup skał skandynawskich (północnych — paleozoicznych i starszych oraz bardzo rzadko spotykanych na terenie Polski skał triasowych i jurajskich): skały krystaliczne (Kr), wapienie (W_P), dolomity (D_P) piaskowce i kwarcyty (P_P), kwarc (Q), oraz lokalnych (trzeciorzędowych i kredowych): wapienie i margle (W_L), piaskowce (P_L) oraz mułowce i iłowce (M_L). Następnie oblicza się wskaźniki petrograficzne O/K-K/W-A/B charakteryzujące zależności między udziałem różnych grup skał skandynawskich (północnych) w żwirach glin zwałowych, gdzie: O — suma skał osadowych ($W_P + D_P + P_P$ + łupki północne), K — suma skał krystalicznych i kwarcu północnego ($Kr + Q_P$), W — suma skał węglanowych ($W_P + D_P$), A — suma skał nieodpornych na niszczenie ($W_P + D_P$ + łupki północne), B — suma skał odpornych ($Kr + Q_P + P_P$).

Stosowana na Litwie analiza składu petrograficznego żwirów (próbki zawierające ok. 300 ziaren o średnicy 5–10 mm) z glin zwałowych obejmuje: skały krystaliczne, kwarc północny, skalenie i podrzędnie kwarcyty (w przybliżeniu odpowiadające w polskiej metodzie sumie skał krystalicznych i kwarcu północnego — $Kr + Q_P$); jotnickie, paleozoiczne i mezozoiczne piaskowce, rzadko mułowce (w polskiej metodzie piaskowce północne — P_P); dewońskie dolomity (w polskiej metodzie dolomity północne — D_P); wapienie organogeniczne ordowiku i syluru oraz pozostałe wapienie paleozoiczne, triasowe i jurajskie (w polskiej metodzie łącznie wapienie północne — W_P; a także kredowe margle (w polskiej metodzie w przybliżeniu wszystkie skały lokalne — głównie, trudne do rozdzielenia, wapienie i margle kredowe i paleoceńskie — $W_L + P_L + M_L$).

W opracowaniach litewskich zawartość procentową tych skał przedstawia się w formie słupkowej. Wartość 100% słupka dopełniają, podobnie jak w metodzie polskiej, krzemienie, lidyty, fosforyty i in. A. I. Gaigalas (1979) prezentuje wyniki badań petrograficznych również w postaci histogramu ukazującego różnice w zawartości żwirów różnych skał dla poszczególnych kompleksów glin zwałowych w stosunku do średniej zawartości tych żwirów obliczonych dla wszystkich glin z wielu profilów danego regionu. Histogram taki został przekazany stronie polskiej w 1995 r. Przedstawia on uśrednioną charakterystykę petrograficzną glin zwałowych z rejonu Vištytis (fig. 3). Identyczną metodą wykonano uśrednienie dla analizowanych w niniejszym opracowaniu glin zwałowych (fig. 4).

Materiał geologiczny pochodzi z sześciu otworów wiertniczych zlokalizowanych na pograniczu polsko-litewsko-rosyjskim w rejonie Wiżajn (fig. 1). Pięć otworów (Żytkiejmy Nadleśnictwo, Żytkiejmy, Bolcie, Stankuny i Poszeszupie) wykonano po stronie polskiej w ramach realizacji arkuszy *SMGP*: Żytkiejmy, Wiżajny i Poszeszupie. Po stronie litewskiej wykonano otwór Norvydai, którego profil był badany w ramach współpracy polsko-litewskiej. W analizowanych profilach wyróżniono osady ośmiu zlodowaceń i określono ich pozycję stratygraficzną. Nawiązano do wyników badań i klasyfikacji litostratygraficznej z centralnej części Pojezierza Mazurskiego (S. Lisicki, 1996*a, b*, 1997) i Niziny Augustowskiej (A. J. Czerwonka, D. Krzyszkowski, 1995).

Przyjęta korelacja litostratygraficzna glin zwałowych Polski północno-wschodniej i południowej Litwy przedstawia się następująco:

— gliny kompleksu Dzukija odpowiadają glinie starszego stadiału zlodowacenia nidy N_1;

— gliny kompleksu Dainava odpowiadają glinie młodszego stadiału zlodowacenia nidy N_2;

— gliny kompleksu Žemaitija, charakteryzujące się maksymalną zawartością dolomitów (D_P), odpowiadają glinie zlodowacenia wilgi (G) i zlodowacenia liwca (C), być może również glinie zlodowacenia sanu S_1 i S_2;

— gliny kompleksu Medininkai to nie gliny zlodowacenia warty W_1 i W_2, ale gliny zlodowacenia odry O_1 i O_2;

— gliny kompleksu Grūda odpowiadają glinie starszego stadiału (świecia) zlodowacenia wisły B_1;

— gliny kompleksu Baltija odpowiadają glinie młodszego stadiału (leszczyńsko-pomorskiego) zlodowacenia wisły B_2.

Korelację litostratygraficzną (tab. 5) skonstruowano na bazie korelacji stratygraficznej plejstocenu Polski i Litwy według J. Satkunasa i in. (1996). W tabeli brak litewskich odpowiedników zlodowacenia narwi A, sanu S i warty W. Brak glin zwałowych zlodowacenia narwi można tłumaczyć brakiem tego kompleksu w rejonie Vištytis (południowa Litwa). Rzadko występujące na Pojezierzu Suwalskim gliny zwałowe zlodowacenia sanu cechuje zbliżona do glin kompleksu Žemaitija charakterystyka petrograficzna, choć te pierwsze wykazują nieco podwyższoną zawartość skał krystalicznych (Kr). To podobieństwo być może spowodowało włączenie glin zlodowacenia sanu do kompleksu litostratygraficznego Žemaitija, który odpowiada prawdopodobnie glinom zlodowacenia wilgi G i liwca C. Gliny zwałowe zlodowacenia warty są cienkie (do kilku metrów grubości) i przeważnie występują wśród miąższego kompleksu piaszczysto-żwirowego rozdzielającego poziomy morenowe zlodowacenia odry O_1 i O_2 i wisły B_1 i B_2 (fig. 4). Być może słabe wykształcenie glin zlodowacenia warty W_1 i W_2 w rejonie pogranicza polsko–litewskiego spowodowało pominięcie ich po stronie litewskiej w charakterystyce petrograficznej i litostratygraficznej. Geolodzy litewscy niesłusznie włączyli cały wspomniany kompleks piaszczysto-żwirowy do zlodowacenia wisły (Nemunas).

Przedstawiony materiał upoważnia do sformułowania następujących wniosków:

1. Wydzielone przez A. I. Gaigalasa kompleksy litostratygraficzne plejstocenu rejonu Vištytis (fig. 2) odpowiadają niektórym poziomom litostratygraficznym wydzielonym w rejonie Wiżajn (fig. 3).

2. Południowolitewskie kompleksy litostratygraficzne o określonej od lat pozycji stratygraficznej wiekowo często nie odpowiadają przyporządkowanym im poziomom litostratygraficznym na terenie Polski (tab. 5).

3. Do przedstawionego w tabeli 5 schematu podziału stratygraficznego Polski i Litwy nie pasuje schemat litostratygraficzny opracowany przez A. I. Gaigalasa dla rejonu południowej Litwy. Kompleksy: Dainava, Žemaitija i Medininkai nie odpowiadają wyróżnionym w tabeli piętrom chronostratygraficznym o takiej samej nazwie. Wydaje się ponadto, że kompleks Žemaitija można korelować z glinami zlodowacenia liwca C i (lub) wilgi G, a może nawet i zlodowacenia sanu S_1 i S_2. W Polsce północno-wschodniej gliny zwałowe zlodowacenia wilgi G i liwca C rozdzielają zbadane palinologicznie osady interglacjału mazowieckiego M. Na terenie południowej Litwy nie wyróżniono kompleksów litostratygraficznych odpowiadających zlodowaceniom narwi A_1 i A_2, sanu S_1 i S_2 i warty W_1 i W_2.

4. Określenie pozycji stratygraficznej glin zwałowych południowej Litwy jest dyskusyjne. Zdaje się świadczyć o tym również pogląd A. I. Gaigalasa mówiący o różnym, regionalnym wykształceniu petrograficznym równowiekowych kompleksów glacjalnych Litwy. Pogląd ten jest sprzeczny z rysującym się dość jednolitym obrazem petrograficznym równowiekowych glin zwałowych Polski północno-wschodniej. Być może ponowna, przestrzenna korelacja kompleksów glin zwałowych Litwy doprowadzi do większego ujednolicenia ich obrazu petrograficznego, a tym samym do pełnej zgodności litostratygraficznej i stratygraficznej osadów plejstoceńskich na obszarze Litwy i Polski północno-wschodniej.