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THE FIRST RECORD OF RED TILL LITHOTYPE IN WESTERN POLAND AND ITS IMPLICATION FOR GLACIAL STRATIGRAPHY AND PALAEOGEOGRAPHY

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Abstract: The first site in western Poland with a red till lithotype has been discovered in the Trzebnica Hills, southwestern Poland. This is a clay-rich, red till with dominant East-Baltic material (East-Baltic lithotypes). The red till forms the uppermost part of the Borowiec Till, a till from the Sanian 2 (Elsterian) Glaciation. Moreover, some Borowiec tills in the Barycz River valley (north) and the Prosna River valley (east) contain in their uppermost parts a dolomite-rich horizon, which, although only greyish-brown, also represents the East-Baltic till lithotypes. The late Elsterian ice sheet in Poland was developed as several ice-lobes with different ice dynamics. The lobes from western Poland advanced to their maximum extent earlier than the eastern lobes. In the latest phase of the glaciation, the western lobes retreated, while the eastern ones advanced from NE to SW. Their presence is proved by deposition of the Borowiec Till and East-Baltic till lithotypes.

Key words: till petrography, red till lithotype, Elsterian, western Poland.

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INTRODUCTION

The red till lithotype was first described from the zone of maximal extent of the Scandinavian ice sheet in eastern (Berendt, 1886) and northern (Gagel, 1910) Germany.

This area contains the largest number of sites bearing this type of till, mostly in Schleswig-Holstein (Stephan, 1980, 1987, 1995, 1998; Meyer, 1981; Kabel, 1982; Ehlers, 1983a,b; Ehlers & Stephan, 1983), northern Meklemburg (Ludwig, 1964), and eastern part of Lower Saxony (Ivanoff, 1984; Gauger & Meyer, 1970; Meyer, 1976). Tills of this type have not been found in western part of Lower Saxony, but they occur in the Netherlands (Rappol, 1983, 1987). Synthetic studies concerning the occurrence of red tills in NW Europe were published by Woldstedt and Duphorn (1974), Ehlers *et al.* (1984), and Ehlers (1992).

The main lithotype of red tills is defined as brown-red or red till, bearing a large proportion of clay (clayey till) and debris derived chiefly from the eastern portion of the Baltic Sea depression, *i.e.* Palaeozoic limestones, Devonian and – rarely – Rotliegendes dolomites and red sandstones and siltstones. Other red tills contain red sandstones and conglomerates of Early Cambrian age, and red crystalline rocks derived from Åland Islands and Finland (Kabel, 1982; Ehlers, 1992). Occurrence of red till lithotype in the southern and western, maximal extent of Pleistocene glaciations in Europe clearly points to glaciation centre placed in the NE part of the Fennoscandian Shield and to glacial transport proceeding along the eastern periphery of the Baltic basin, through the Baltic states, and then along southern Baltic; generally from the east to the west.

Other properties of red till occurrence have been observed in Germany (Stephan & Kabel, 1982; Ehlers *et al.*, 1984; Ehlers, 1990, 1992). These tills occur only on top of other tills, *i.e.* sand-silty, grey or greyish-brown tills, containing debris derived from the Fennoscandian Shield and the central and southern parts of the Baltic Sea basin, without being separated by glaciofluvial or other sediments. The top red tills are between a dozen or so centrimetres to a few metres thick. These were mainly found in top parts of tills dated to the older Saalian stadial (= Drenthe, Saale I; both in Germany and the Netherlands), as well as on top of tills of the younger Saalian stadial (the so-called Warthe Till overlying the Fuhlsbüttler Till; composing jointly the Saale III horizon). The red till lithotype has not been observed within tills of the medial Saalian stadial (Saale II), although the latter commonly contain more East-Baltic material compared to the Drenthe tills (Ehlers *et al.*, 1984; Ehlers, 1990, 1992).

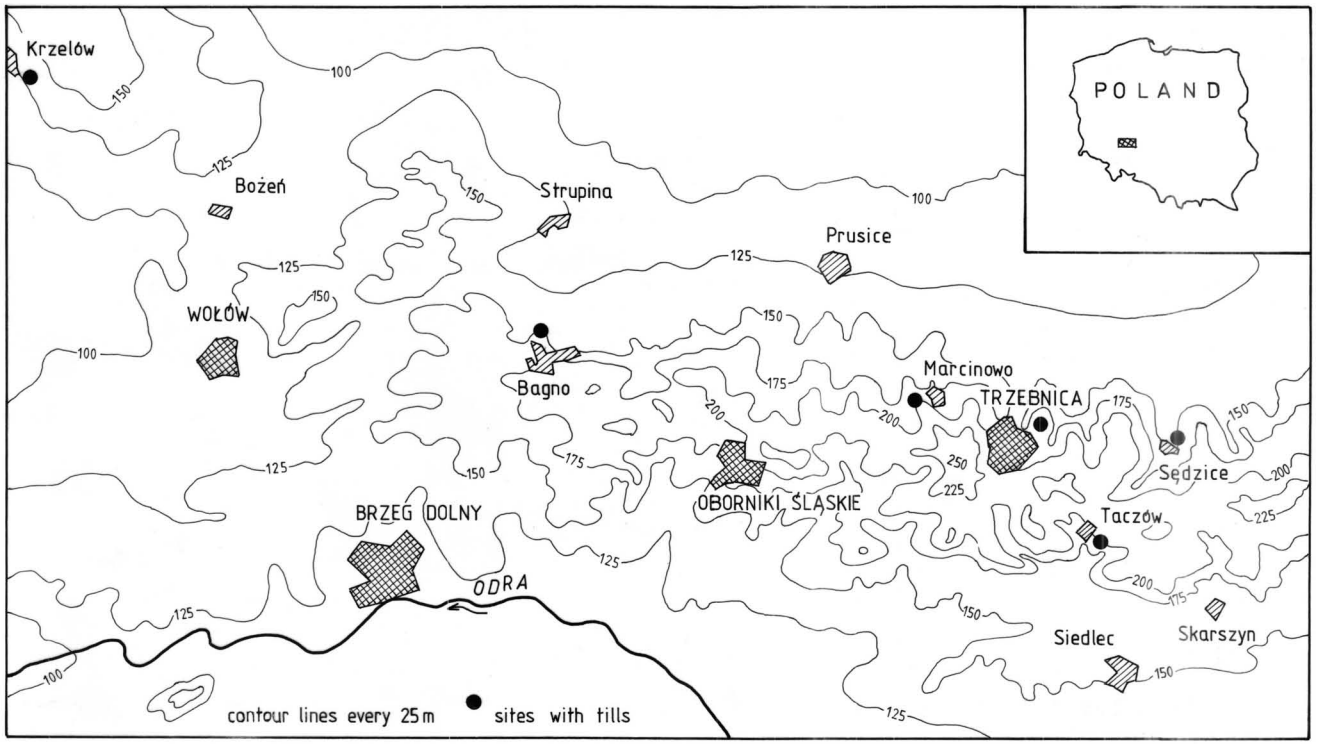


Fig. 1. Location of sites with glacial tills in the Trzebnica Hills. Red tills occur at Marcinowo

In eastern Germany, dolomite-rich tills of the East-Baltic lithotypes, although devoid of red colour, were documented for Saale II and III glaciations (Cepek, 1969; Eissmann & Müller, 1979; Böse, 1989). Tills of the East-Baltic facies, however, occur here within belts of restricted geographic extent, and dolomites within such belts are abundant within the entire section of the till. In exceptional cases, red tills are to be found in Germany within glacial sediments of Elsterian age (Jordan & Kuhn, 1975; Jordan, 1975).

Occurrence of red tills or dolomite-rich tills in stratigraphic section points to the glacier changeable transport directions as well as glaciation centres during every, single glacier advance. In earlier phases of glacial advance, transport from the north (*i.e.* Sweden) to the south prevailed, being later systematically replaced by NE–SW direction, and finally proceeding from the east to the west, *i.e.* from Finland and Estonia (Ehlers *et al.*, 1984; Ehlers, 1992).

OCCURRENCE OF RED TILLS AND DOLOMITE-RICH TILLS IN POLAND

Tills of the East-Baltic lithotypes (dolomite-rich) in Poland commonly occur in the Suwałki Lakeland district (Kenig, 1991, 1998; Czerwonka & Krzyszkowski, 1995; Ber 1996; Ber *et al.* 1998; Lisicki 2003; Krzyszkowski & Czerwonka, 2007). Moreover, nearly all till horizons in this area comprise a large proportion of dolomite (5%), the Palaeozoic limestones being dominant. Some till horizons contain even more dolomite (20–40%) than Palaeozoic limestones. Czerwonka and Krzyszkowski (1995) and Krzyszkowski and Czerwonka (2007) documented two horizons of such tills in a few borehole logs in Augustów area, and assigned them to the South-Polish (Elsterian) Glaciation (*cf.* also Ber *et al.*, 1998). In some sections, dolomite-rich tills are red in colour and more clayey compared to other tills typical for this region. However, other dolomite-rich tills are grey-brown and largely composed of sand-silty material. It can be inferred, therefore, that the till colour (red tills) does not depend directly on petrographic composition (tills of the East-Baltic lithotypes). Most probably, red colour comes from red sandstones and siltstones or weathered Rotliegendes and Devonian rocks, which occasionally occur in tills. In the Suwałki Lakeland district, there also occur dolomite-rich tills, which tend to be confined to several belts oriented NE–SW (within two horizons of tills of the South-Polish Glaciation), separated by belts composed of tills bearing a relatively smaller amount of dolomite (Czerwonka & Krzyszkowski, 1995, Ber, 1996; Ber *et al.*, 1998; Lisicki, 2003; Krzyszkowski & Czerwonka, 2007). Tills of the East-Baltic lithotypes, including red tills, were also found in the Mazury Lakeland (Lisicki, 1996, 1997, 2003), although showing less extensive distribution.

Tills of the East-Baltic lithotypes rarely occur in western Poland. There dominate tills rich in crystalline rocks (N–S transport) or bearing equal proportions between crystalline rocks and Palaeozoic limestones (NE–SW transport). A few till horizons containing more Palaeozoic limestones than crystalline rocks were found in this area, like for instance: tills of the Wierzbno type in Silesian Lowland (Czerwonka & Krzyszkowski, 1992a), tills of the Witosław, Górzno and Bytyń types in middle Wielkopolska region (Czerwonka & Krzyszkowski, 1994), or tills of the Borowiec type in the Barycz River valley (Czerwonka *et al.*,

Table 1

Till stratigraphy in Trzebnica Hills and surrounding areas

Pleistocene	Weichselian *(North Polish Complex)*	Bytyń Till		
		Maliniec Till		
	Eemian			
	Saalian *(Middle Polish Complex)*	Wartanian	Mutowo Till	
			Kopaszewko/Górzno Till	
			Karolewo/Naratów Till	
			Taczów Till	
		Pilician		
		Odranian	Dopiewiec/Smolna Till	
	Zbójnian			
			?	
			?	
	Mazowian			
	Elsterian *(South Polish Complex)*		*Borowiec Till*	***East***
		Sanian 2	Wierzbno/Witosław Till	***Baltic***
				Facies
		Pyroxene Series		
		Sanian 1	Krzesinki Till	
		Nidian	Grońsko/Pietrzykowice Till	
	? Preglacial deposits			
Pliocene				

1997), but the content of dolomite within these tills does not exceed 5 to 6 per cent. Only two till horizons of the late Warthe age, found in Konin region (Stankowski & Krzyszkowski, 1991) and in middle Wielkopolska area (Czerwonka & Krzyszkowski, 1994), *i.e.* the Kopaszewko and Mutowo-type tills, do contain a large proportion of dolomite, namely 5–12% and 5–10%, respectively. These tills used to be the only East-Baltic lithotype tills in western Poland, none of them of red colour. All till sites showing clear influence of the East-Baltic facies were recognized in borehole logs.

A new site of the East-Baltic lithotypes tills, red in colour, were found at Marcinowo in Trzebnica Hills (Fig. 1). These tills probably represent a younger stage of the South-Polish (Elsterian) Glaciation.

TILL STRATIGRAPHY IN TRZEBNICA HILLS AND SURROUNDING AREAS

The most important section at Trzebnica exposes two tills described by Krzyszkowski (1992): the older till, correlated with the Wierzbno-type till from Silesian Lowland (Sanian 2 Glaciation), and the younger one, correlated with the Smolna-type till (Odranian Glaciation; Czerwonka & Krzyszkowski, 1992a) (Table 1). Moreover, Winnicki (1991) suggested presence of two tills of the South-Polish Complex (Sanian 1 and Sanian 2 glaciations) in this area; a fact later confirmed by Czerwonka *et al.* (1997). These authors identified in borehole logs from Trzebnica Hills at least two tills of the South-Polish Complex (of the Wierzbno and Krzesinki types), and deemed probable the occur-

Table 2

Till petrography in Trzebnica Hills and their northern and eastern forelands, with special reference to tills with East-Baltic lithotypes

Till	Site	O/K	K/W	A/B	%Dp	Dp/Wp	Σ_L	W_L	P_L	M_1	M_2	Q_L	Kz	F	R	C	I_L
Smolna	Smolna	0.96	1.25	0.74	1.1	0.03	16	2	7	1	3	3	+	-	-	-	-
Wierzbno	Wierzbno	1.20	0.90	1.00	2.2	0.05	7.1	2	2	1	±	+	2	-	-	±	-
Witosław	Witosław	1.42	0.75	1.23	2.6	0.06	20	2	3	-	2	10	+	±	+	±	-
Borowiec	Borowiec	1.49	0.74	1.34	4.7	0.10	14	2	2	±	±	4	2	+	-	2	-
Smolna	Bagno	0.72	1.47	0.65	0.0	0.00	37	-	-	+	-	24	2	-	-	-	10
Wierzbno	Krzelów	1.35	0.78	1.20	3.1	0.08	26	4	3	-	-	12	4	-	-	-	3
Borowiec?Wierzbno?	Sędzice	1.47	0.69	1.44	0.0	0.00	14	±	1	±	1	8	2	±	-	-	-
Borowiec	Taczów	2.33	0.44	2.20	1.1	0.02	9	2	+	2	-	4	-	+	-	-	-
Borowiec B	Marcinowo	6.74	0.15	6.74	12.0	0.17	3	-	-	1	1	+	+	-	-	-	-
Borowiec A	Marcinowo	3.20	0.30	3.20	1.7	0.03	7	-	-	+	±	5	1	-	-	-	-
Borowiec B	Czerlejewo	1.67	0.61	1.57	11.0	0.27	13	3	2	±	1	4	+	-	1	1	-
Borowiec A	Czerlejewo	1.80	0.61	1.42	3.8	0.08	10	1	1	+	±	4	1	±	±	2	-
Borowiec B	Nowe Domy	1.65	0.67	1.37	8.4	0.21	15	5	2	+	±	4	+	±	+	2	+
Borowiec A	Nowe Domy	1.40	0.77	1.21	4.9	0.12	14	5	+	-	-	4	1	±	+	2	±
Borowiec B	Rudniczysko	1.71	0.60	1.57	9.7	0.23	9	±	2	+	-	5	1	±	±	±	-
Borowiec A	Rudniczysko	1.53	0.69	1.36	3.9	0.12	11	+	2	±	1	4	1	±	-	-	-
Borowiec B	Granice	1.42	0.76	1.22	9.5	0.24	10	-	-	-	-	4	±	-	-	-	5
Borowiec A	Granice	1.80	0.57	1.70	3.5	0.08	9	4	-	-	-	2	±	+	-	-	2

O – total of sedimentary rocks (Wp+Dp+Qp+Pp+I), K – total of crystalline rocks (Kr), W – total of carbonate rocks (Wp+Dp), A – total of non-resistant rocks (Wp+Dp+I), B – total of resistant rocks (Kr+Pp+Qp); Σ_L – total, W_L – limestones, P_L – sandstones, M_1 – Palaeogene mudstones, M_2 – Neogene mudstones, Q_L – milk quartz, Kz – flint, F – phosphorite concretions, R – pyrite concretions, C – lignite, I_L – other rocks

rence of the third, oldest till of the Pietrzykowice type. They also found two tills of the Middle-Polish (Saalian) Complex: the Smolna Till (Odranian Glaciation) and Taczów Till (Wartanian/Warthe Glaciation) types. The Taczów Till attains a characteristic geological position: it is usually not disturbed, occurs at the groundsurface (apart from Weichselian loesses), and discordantly overlies older, strongly glacitectonically disturbed tills (Krzyszkowski, 1993; Czerwonka *et al.*, 1997). A similar till succession, composed of three South-Polish and two Middle-Polish Complexes tills, was found immediately to the north, in the Barycz River valley (Czerwonka *et al.*, 1997), where glacial sediments are not disturbed and tills form a normal stratigraphic succession. Moreover, in the Barycz River valley, position of the youngest South-Polish till (Sanian 2) is occupied by two petrographically different till types, *i.e.* the Wierzbno and Borowiec tills. The former contains a slightly increased amount of Palaeozoic limestones in respect to crystalline rocks (K/W 0.8–0.9), while the latter is clearly dominated by limestones (K/W 0.6–0.8). The content of dolomite in these two tills does not exceed 6% (Table 2). The two tills were also found farther to the east, in the upper Pilica River valley (Czerwonka *et al.*, 1998). Except one borehole, the Wierzbno and Borowiec tills occur separately and never in superposition, but always in the same stratigraphic position, *i.e.* above the Krzesinki-type tills and below the Smolna-type tills. They also occur side by side, since boreholes piercing individual till types are only a few to a dozen or so kilometres apart (Czerwonka *et al.*, 1997, 1998). In one borehole log, at Blizocin, tills of the Borowiec type overlie those of the Wierzbno type, being separated by a *ca*. 10-m-thick layer of sands and ice-dammed lake sediments (Czerwonka *et al.*, 1997). However, the borehole in question is situated at the periphery of a glacitectonically disturbed area; hence, both till horizons may not occur *in situ*. In addition, the results of laboratory analysis of the "younger" horizon come from one sample only, what makes interpretation of the Borowiec-type till as representing a separate and younger glacier advance problematic.

The existing exposures in Trzebnica Hills do not allow for establishing reliable till stratigraphy. It is only at Trzebnica, where two tills of the Wierzbno and Smolna types occur (Krzyszkowski, 1992). Moreover, Krzyszkowski and Łabno (2002) described from Bodowice site in Dalków Hills two other tills in superposition, of the Smolna and Taczów types. The remaining sites expose only single till horizons, which are usually strongly folded. Their stratigraphic position can only be inferred from petrographic studies and correlation with stratotype sections located in Silesian Lowland or in the Barycz River valley.

Exposure at Bagno (Fig. 2) most probably includes the Smolna-type till, in which, within Scandinavian material, crystalline rocks dominate (K/W 1.47), dolomites are absent, and local rocks are represented by milk quartz (Table 2). These properties are comparable to those of the Smolna-type tills at Trzebnica (Krzyszkowski, 1992) and in

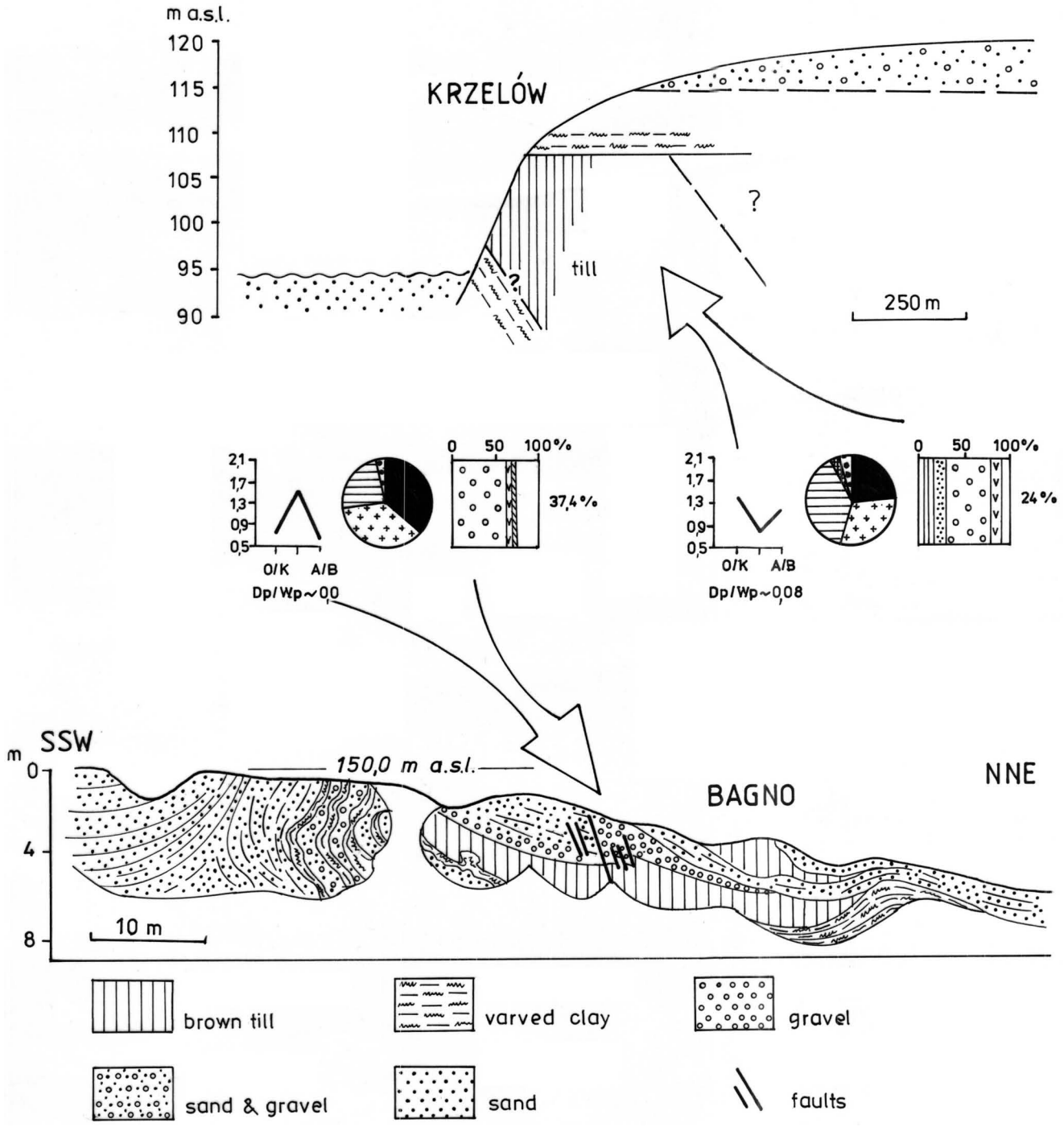


Fig. 2. Geological setting and petrography of tills at Bagno (Smolna Till) and Krzelów (Wierzbno Till). For explanation see Fig. 5

Silesian Lowland (Czerwonka & Krzyszkowski, 1992a). At Krzelów (Fig. 2), in turn, a till comparable to that of the Wierzbno type occurs: with Palaeozoic limestones slightly dominating over crystalline rocks (K/W 0.78), and the amount of dolomite being moderate (3.1%). Tills exposed at Taczów (Fig. 3) are decisively dominated by Palaeozoic limestones (62%) in respect to crystalline rocks (27%; K/W 0.44); the amount of dolomite being *ca*. 1%. Local rocks are mostly represented by milk quartz, Mesozoic limestones, and Palaeogene siltstones. Despite small amount of dolomite, the till from Taczów can be relatively safely correlated with the Borowiec-type tills; it is the only till in this area, in which limestones dominate so decisively over crystalline rocks (Czerwonka *et al.*, 1997). Small amount of dolomite within Taczów Till can result from petrographic composition calculated from one sample only (175 grains). Till at Sędzice (Fig. 3) also includes more limestones (51%) than crystalline rocks (34%; K/W 0.7), while dolomites do not occur at all (the till was studied in two samples numbering 270 and 357 grains). Local rocks are dominated by milk quartz; flints, Mesozoic sandstones, and Neogene siltstones being quite abundant as well. The till from Sędzice can rep-

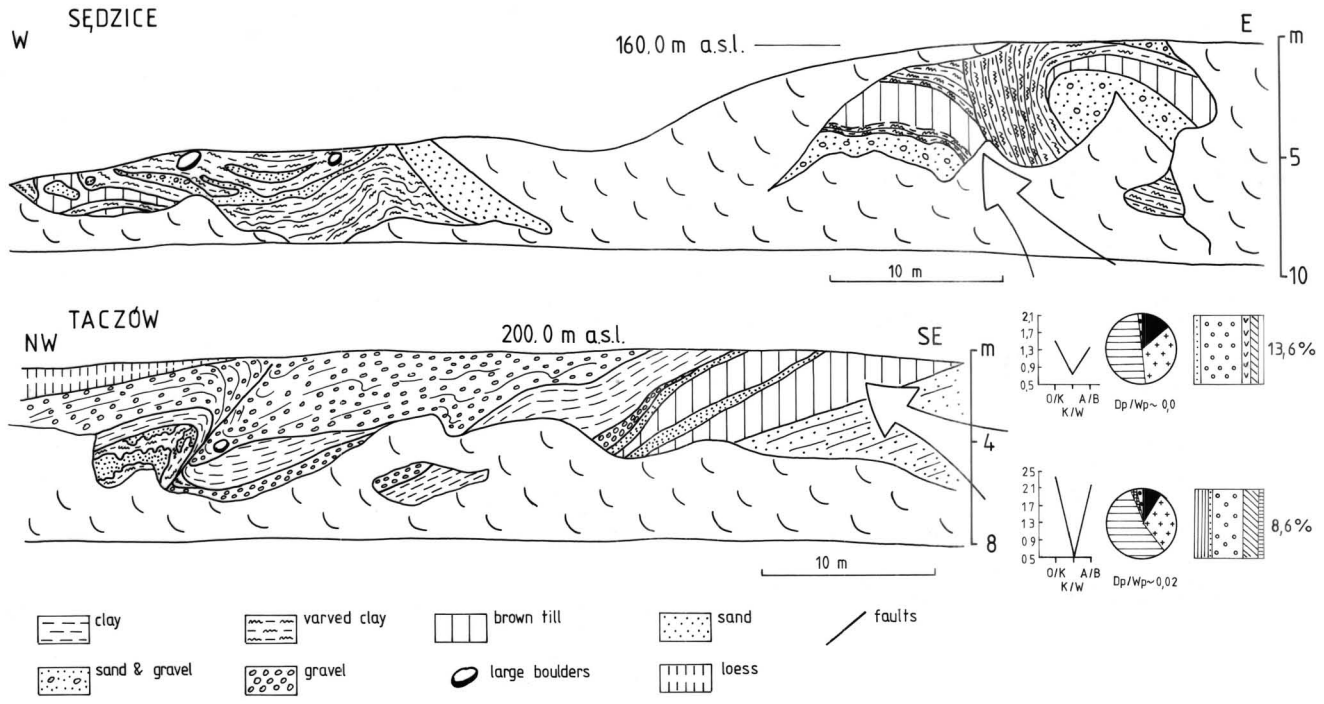


Fig. 3. Geological setting and petrography of tills at Sędzice (Wierzbno or Borowiec Till) and Taczów (Borowiec Till). For explanation see Fig. 5

resent either the Borowiec-type till (ignoring the lack of dolomites) or the Wierzbno-type till, which usually contains less dolomites (0–3%) than the Borowiec Till (3–6%). The K/W index of tills from Sędzice approaches a boundary value between the two till types (Czerwonka *et al.*, 1997) (Table 2). A similar till, showing properties transitional between the Wierzbno and Borowiec types, was described from Weronikopole in Ostrzeszów Hills (Czerwonka *et al.*, 1998). This till, however, bears a relatively large amount of dolomite.

RED TILLS AT MARCINOWO AND THEIR REGIONAL CORRELATION

Site Marcinowo is situated in the central part of Trzebnica Hills, a few kilometres west of Trzebnica (Fig. 1). The exposure includes strongly disturbed clays of the Poznań Series, preglacial sands and gravels, varved clays, glaciofluvial sediments (sands), and tills. Disturbed sediments are discordantly overlain by loess (Fig. 4). The deformed sediments dip nearly vertically or at 60–70° and build three slices. The central slice bears as well a strongly deformed zone (overturned fold?) composed of varved clays and tills (Fig. 4).

Tills are largely brown and silt-sandy; they will be further referred to as basal tills. The hinge part of the fold includes a small, irregular till body of more clayey matrix, red in colour. All tills contain calcium carbonate. The boundary between the tills is well marked, although no erosional contact was found. The tills are only separated by a few centimetres thick layer of greenish-grey till, probably formed due to gley processes at the contact between tills of contrasting lithology. Glacial sediments occur in a strongly disturbed zone; therefore, it can be suggested that the original stratigraphic succession was represented by varved clays at the bottom, brown tills and red tills at the top. One sample from red tills (184 grains) and two samples from brown tills (143 and 222 grains) were collected for further studies.

Petrographic composition of brown tills from Marcinowo resembles that of Taczów Till (Fig. 4; Table 2). Palaeozoic limestones prevail (69%) over crystalline rocks (22%; K/W 0.3), and the content of dolomites is *ca*. 2% (D_p/W_p 0.03). Local rocks (7%) are mainly composed of milk quartz, the amount of flints and Palaeogene siltstones being relatively small. Correlation of these tills with those occurring at Taczów and the Borowiec-type tills is likely. Strong dominance of Palaeozoic limestones over crystalline rocks at Taczów and Marcinowo, and K/W 0.3–0.5 compared to 0.6–0.8 in the typical Borowiec Till, can be either a local characteristic or a result of small frequency of the studied clasts.

Petrographic composition of red tills is comparable to that of brown tills, except dolomite content (Fig. 4; Table 2). Palaeozoic limestones still dominate (72%), at a very small amount of crystalline rocks (13%; K/W 0.15). The share of dolomites is 12% (D_p/W_p 0.17), being considerable larger compared to that in brown clays. The content of local rocks is twice as less (3–4%); there occur milk quartz, flints, and Palaeogene and Neogene siltstones.

The red tills from Marcinowo can be safely considered a typical lithotype of red tills. This lithotype has all characteristics described for such a till type in northern Germany: it is red, more clayey, includes more East-Baltic material (here dolomites), and overlain by tills without break in sedimentation. If correlation of the till from Marcinowo with

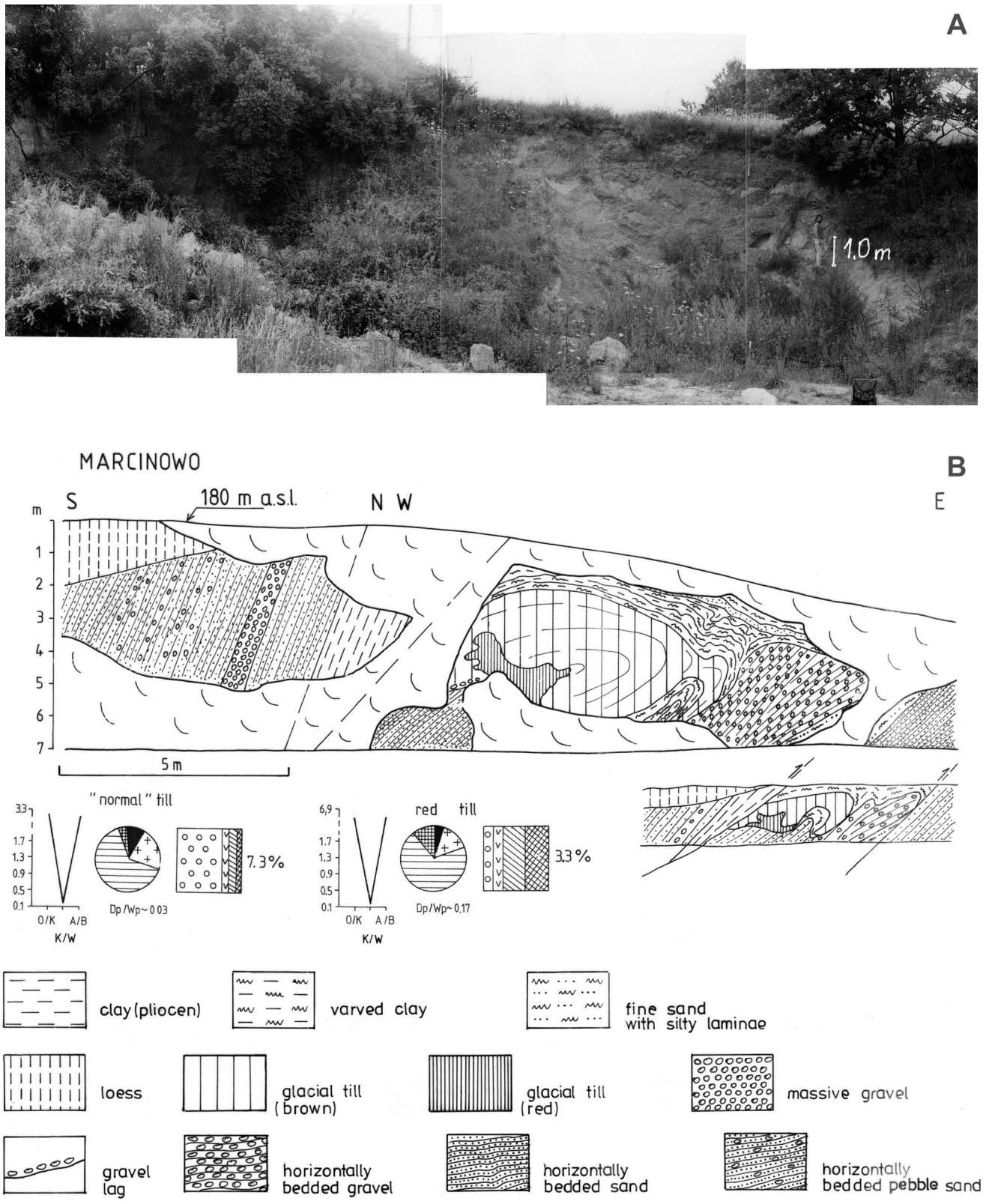


Fig. 4. Geological setting and petrography of tills at Marcinowo: **A** – general overview, **B** – brown till (Borowiec Till) and red till (East Baltic lithotype). For explanation see Fig. 5

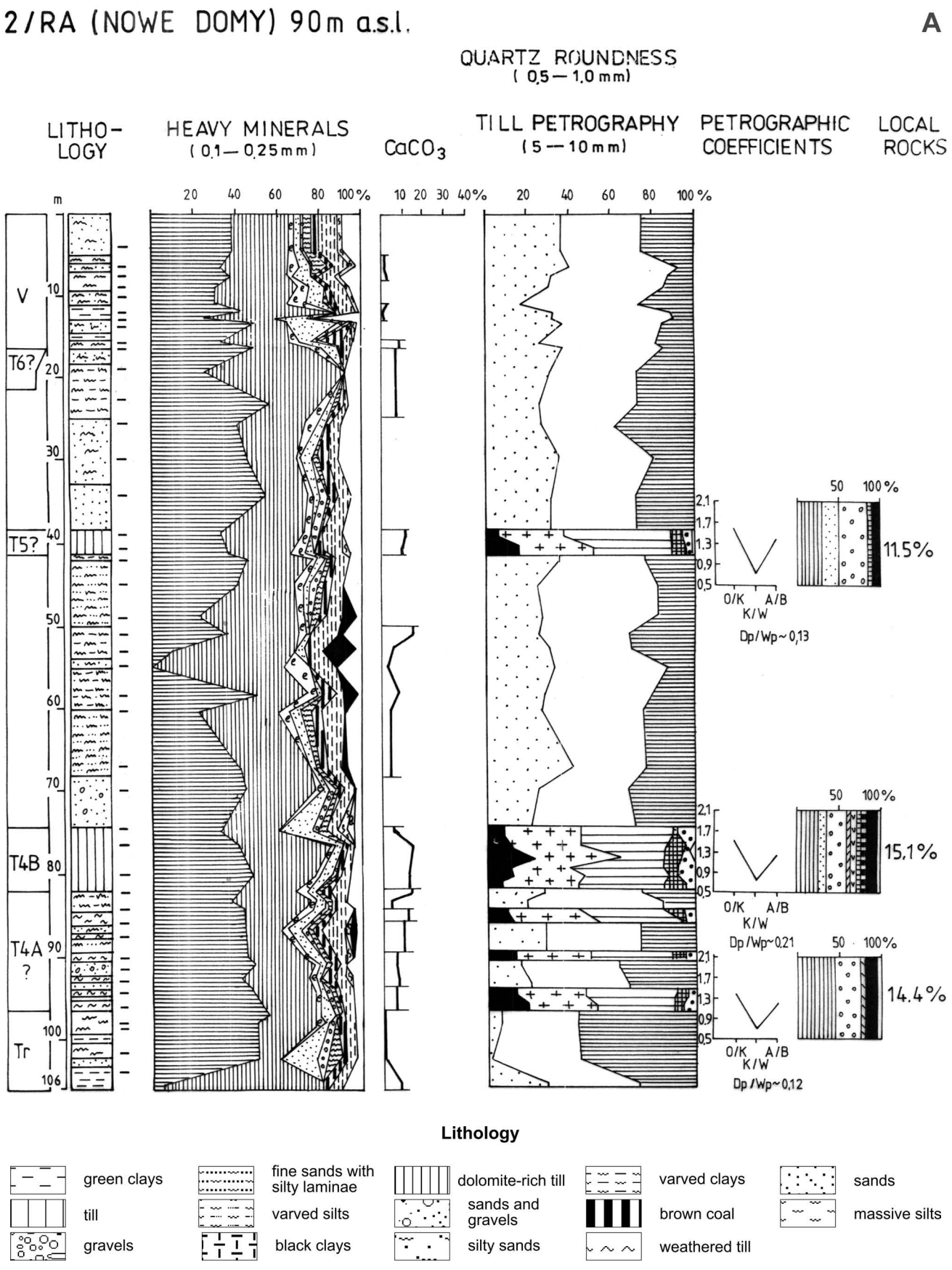
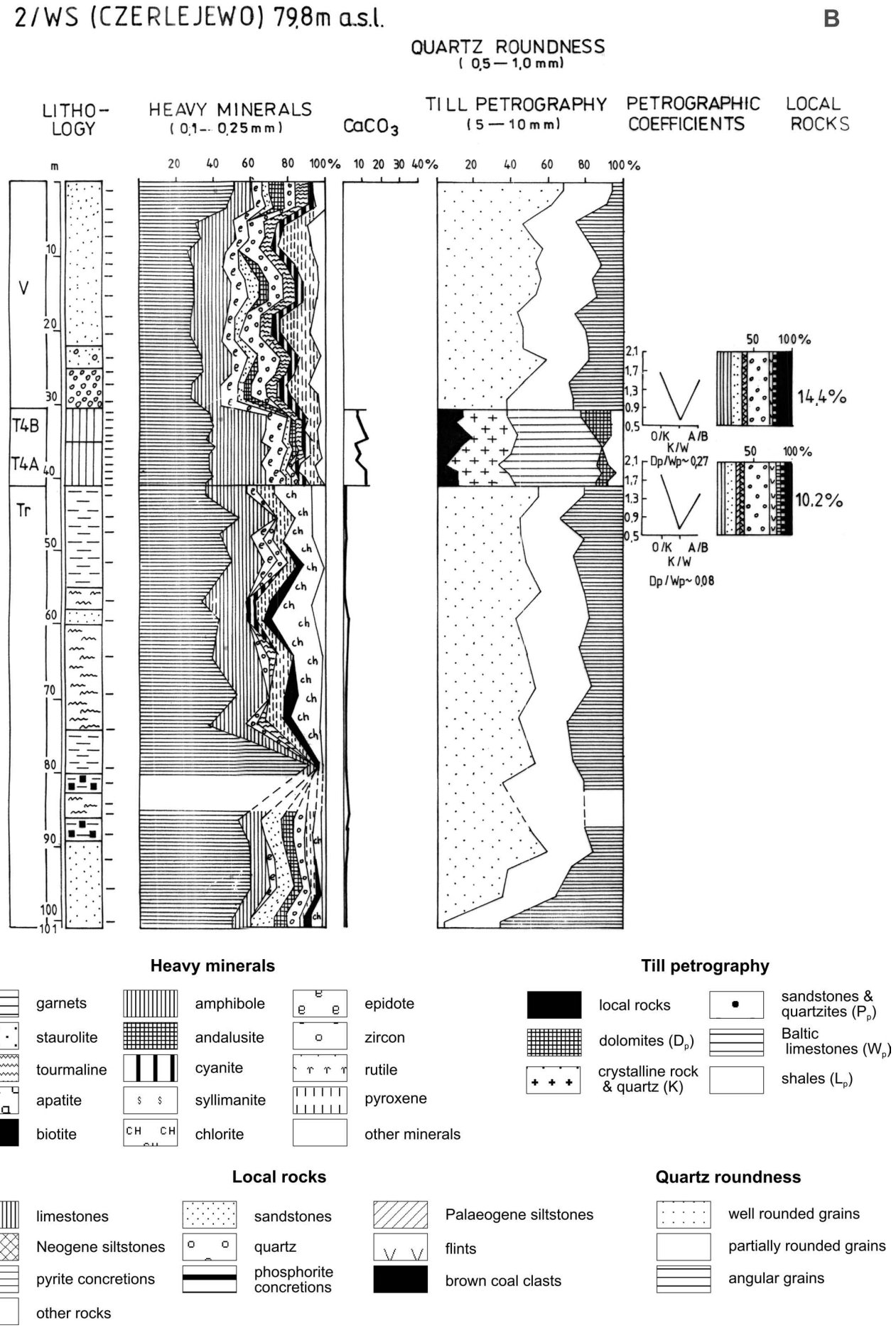


Fig. 5. Geological setting and petrography of tills in Nowe Domy and Czerlejewo sections (Borowiec Till marked as T4, A – till, B – dolomite-rich till)


2/WS (CZERLEJEWO) 79,8m a.s.l.
B
QUARTZ ROUNDNESS
(0,5 — 1,0 mm)
LITHO-LOGY
HEAVY MINERALS
(0,1 — 0,25 mm)
CaCO3
TILL PETROGRAPHY
(5 — 10 mm)
PETROGRAPHIC COEFFICIENTS
LOCAL ROCKS
m
V
T4B
T4A
Tr
O/K A/B K/W
Dp/Wp~ 0,27
Dp/Wp~ 0,08
14,4%
10,2%
Heavy minerals
garnets
staurolite
tourmaline
apatite
biotite
amphibole
andalusite
cyanite
syllimanite
chlorite
epidote
zircon
rutile
pyroxene
other minerals
Till petrography
local rocks
dolomites (Dp)
crystalline rock & quartz (K)
sandstones & quartzites (Pp)
Baltic limestones (Wp)
shales (Lp)
Local rocks
limestones
Neogene siltstones
pyrite concretions
other rocks
sandstones
quartz
phosphorite concretions
Palaeogene siltstones
flints
brown coal clasts
Quartz roundness
well rounded grains
partially rounded grains
angular grains

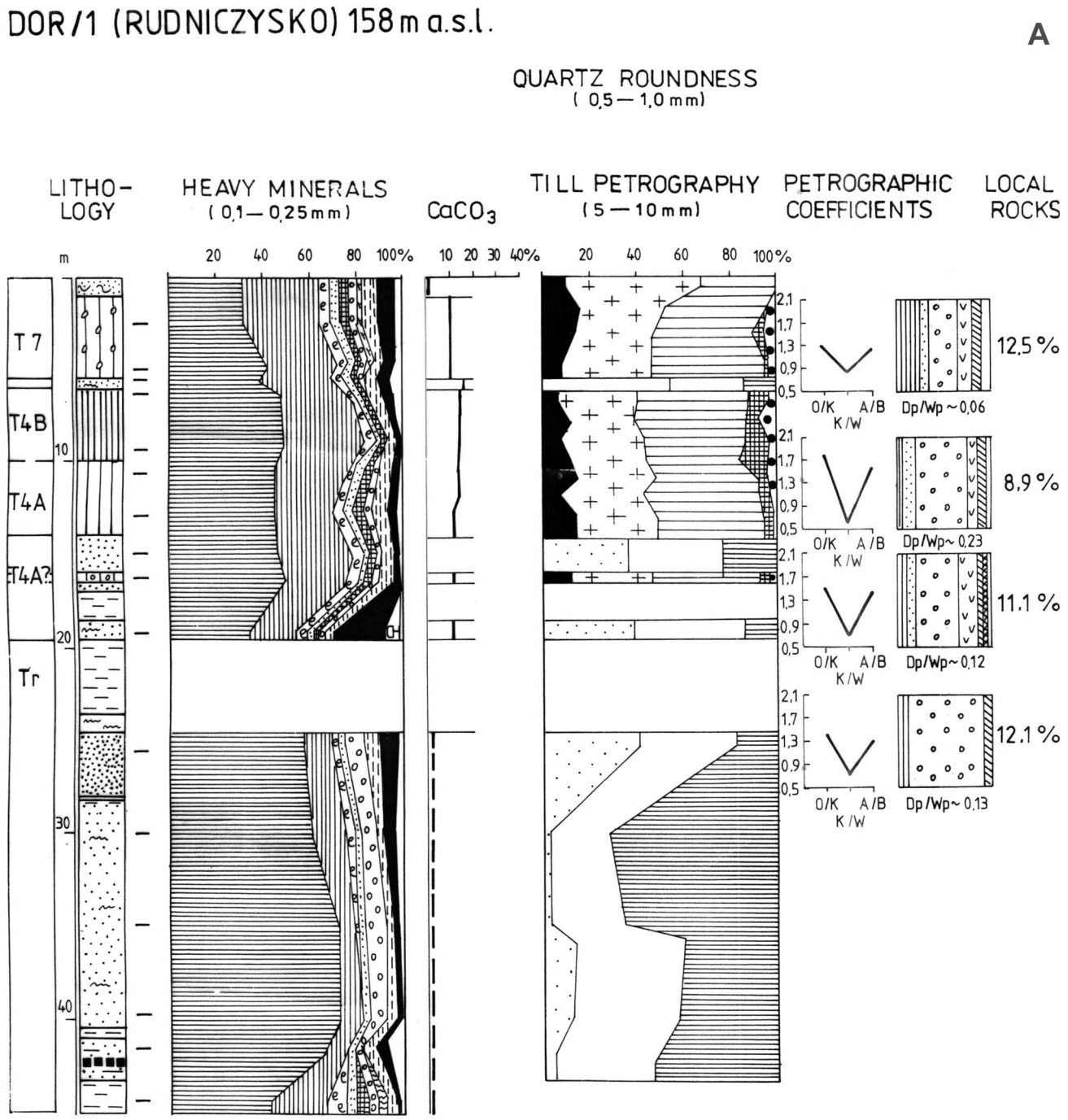
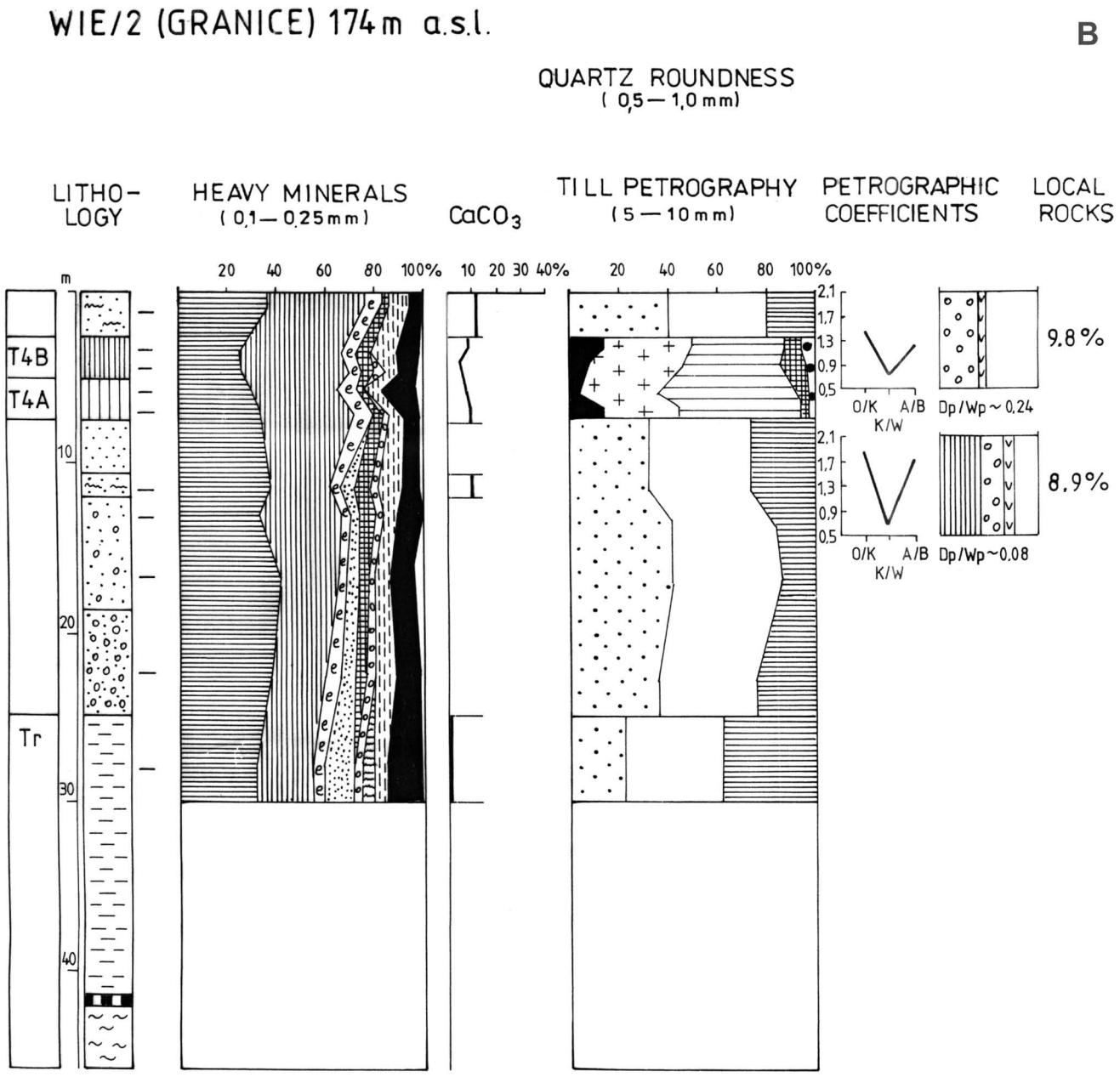


Fig. 6. Geological setting and petrography of tills in Rudniczysko and Granice sections (Borowiec Till marked as T4, A – till, B – dolomite-rich till; T7 Radomina Till from Warta Glaciation). For explanation see Fig. 5

those of the Borowiec type is correct, the described red tills represent the last stage of ice sheet advance from the youngest glaciation of the South-Polish (Elsterian) Complex. Therefore, it is the first described occurrence of East-Baltic lithotype of this glaciation in western Poland.

Analysis of archival data enables one to extend the above interpretation. In the Barycz River valley, two sites with Borowiec-type tills were found: Nowe Domy (sheet Rawicz of the Detailed Geological Map of Poland, 1: 50,000) and Czerlejewo (sheet Wschowa DGMP), showing a characteristic succession of till properties (Fig. 5). In both sections, above tills showing properties typical for the Borowiec type, an additional till layer occurred (without break in sedimentation in case of Czerlejewo site), where the amount of dolomite was two to three times higher, the remaining characteristics being unchanged (Table 2). Both layers, rich in dolomite, were included into the Borowiec-type till as sub-horizons T4A and T4B (dolomitic), respectively (Czerwonka *et al.*, 1997). A similar sequence of characteristics, also without break in sedimentation, was noted in the Borowiec-type till in boreholes Rudniczysko (sheet Doruchów) and Granice (sheet Wieruszów DGMP) in the



upper Prosna River valley (Fig. 6). In all cases, the amount of dolomite increases rapidly: from 2–6% to 8–14% (from sample to sample) (Figs 5, 6). Despite the fact that none of dolomitic sub-horizons (T4B) in the described borehole logs is red, it is likely that they nearly certainly represent the East-Baltic till facies. Therefore, occurrence of this lithotypes in the Borowiec-type tills is of regional character, documented with certainty at five sites: Marcinowo, Czerlejewo, Nowe Domy, Rudniczysko and Granice, spread over a relatively large area (Fig. 7).

DISCUSSION AND CONCLUSIONS

A few questions pertaining to distribution of the East-Baltic lithotypes and red tills in SW Poland need to be discussed in detail. These are as follows:

1. Is the age of Marcinowo tills occurring in a glacitectonically disturbed zone properly established?

2. What is the relationship between the Wierzbno-type tills (and petrographically similar Witosław-type tills in middle Wielkopolska region) and Borowiec-type tills?

3. How to relate the East-Baltic lithotype tills and associated transport directions from the east and NE to the transport directions within other glacial lobes of the same glaciation in Poland?

The occurrence of Marcinowo tills within a disturbed series in Trzebnica Hills makes correlation of these tills with those of the Warthe stage impossible (Krzyszkowski, 1993; Czerwonka *et al.*, 1997, 1998). On the other hand, the only tills showing predominance of Palaeozoic limestones over crystalline rocks within the disturbed series are tills of the Wierzbno type, which represent a younger of the South-Polish Complex (Elsterian) glaciation. Their stratigraphic equivalents in the Barycz and Prosna river valleys are tills of the Borowiec type (Czerwonka *et al.*, 1997, 1998), and in central Wielkopolska region tills of the Witosław type

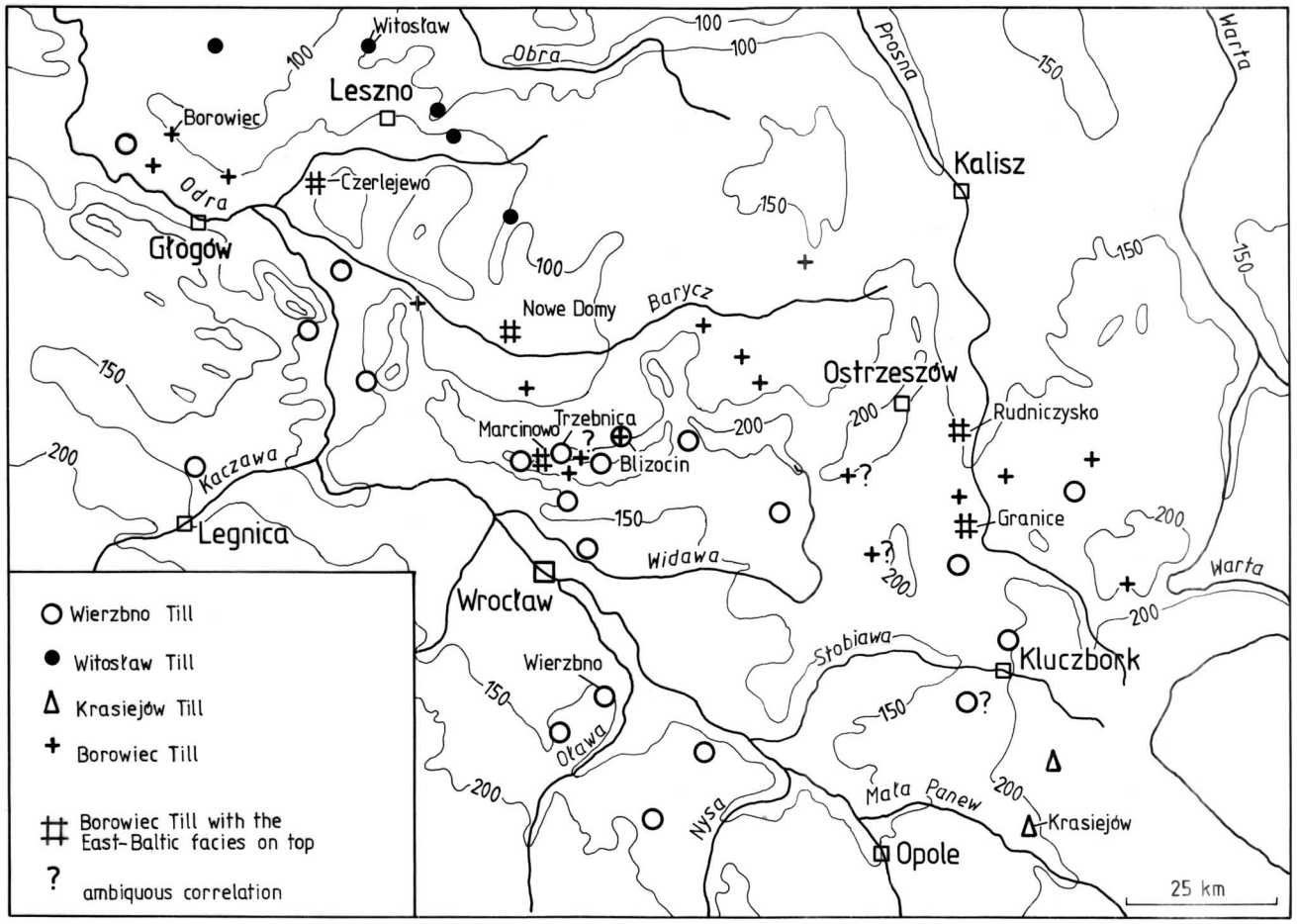


Fig. 7. Distribution of petrographically documented tills of the late Elsterian Glaciation in southwestern Poland. Wierzbno Till represents the Odra lobe, Witosław Till the Warta-Prosna lobe, and the Krasiejów Till the Wisła-Nida lobe. The last one has features comparable with tills of the Bełchatów outcrop (Czerwonka *et al.*, 1998; Czerwonka & Krzyszkowski, 1992b)

(Czerwonka & Krzyszkowski, 1994). Among these till types, the till from Marcinowo shows the closest resemblance to the Borowiec-type tills. Such a correlation is further supported by the occurrence of top East-Baltic lithotypes within both Marcinowo and Borowiec-type tills.

The distribution of sites bearing Borowiec Till is unusual. These tills cluster within a 25–50-km-wide belt, oriented E–W along the present-day Barycz River valley and its periphery (Trzebnica Hills, Kalisz Plateau) and in the upper Prosna River valley (Fig. 7). Moreover, the tills separate somehow the extents of the Wierzbno Till in Silesian Lowland and Witosław Till in central Wielkopolska, showing comparable petrographic characteristics. Only in the southern extent of the Borowiec Till, this till and Wierzbno Till do occur in the same, narrow area (Fig. 7). Assuming the same age of all these three till types (Czerwonka *et al.*, 1997) and general glacier transport from the north or NNE, petrographic composition of the Borowiec Till is difficult to explain. The share of Palaeozoic limestones and layers bearing the East-Baltic lithotypes within the latter horizon is nearly twice as much as in the Witosław Till, occurring immediately to the north. A plausible solution is to assume that the Borowiec-type tills are younger than those of the Wierzbno/Witosław types, and represent a still younger glaciation of the South-Polish Complex. The only problem is that in areas situated farther to the north (Wielkopolska) no tills resembling the Borowiec-type tills were found in a similar stratigraphic position. Moreover, it is likely that in western Poland only three till horizons from the South-Polish Complex occur (Czerwonka & Witek, 1977; Czerwonka & Krzyszkowski, 1992a, 1994; Urbański, 2007), like in other parts of Poland (Mojski, 1969; Rzechowski, 1971, 1974, 1977, 1982).

The following hypothesis can be put forward: the Wierzbno, Witosław and Borowiec-type tills originated from the same glaciation of the South-Polish (Elsterian) Complex, although representing different phases. During glacier advance towards its maximal extent in western Poland, three glacier lobes originated (Fig. 8A): (1) the Odra lobe, in which Wierzbno Till (K/W 0.8–1.1) was deposited, embraced the Silesian Lowland, Sudetic Foothills, and partly hills of the Silesian Rampart, including Trzebnica Hills; (2) the Warta-Prosna lobe, in which Witosław Till (K/W 0.8–0.95) originated, was less dynamic, covered central Wielkopolska region and stopped along Wschowa-Kalisz line, probably without reaching the Odra lobe (*cf.* extent of the Witoslaw Till in Fig. 7); and (3) the Vistula-Nida lobe, which embraced central Poland and probably reached the

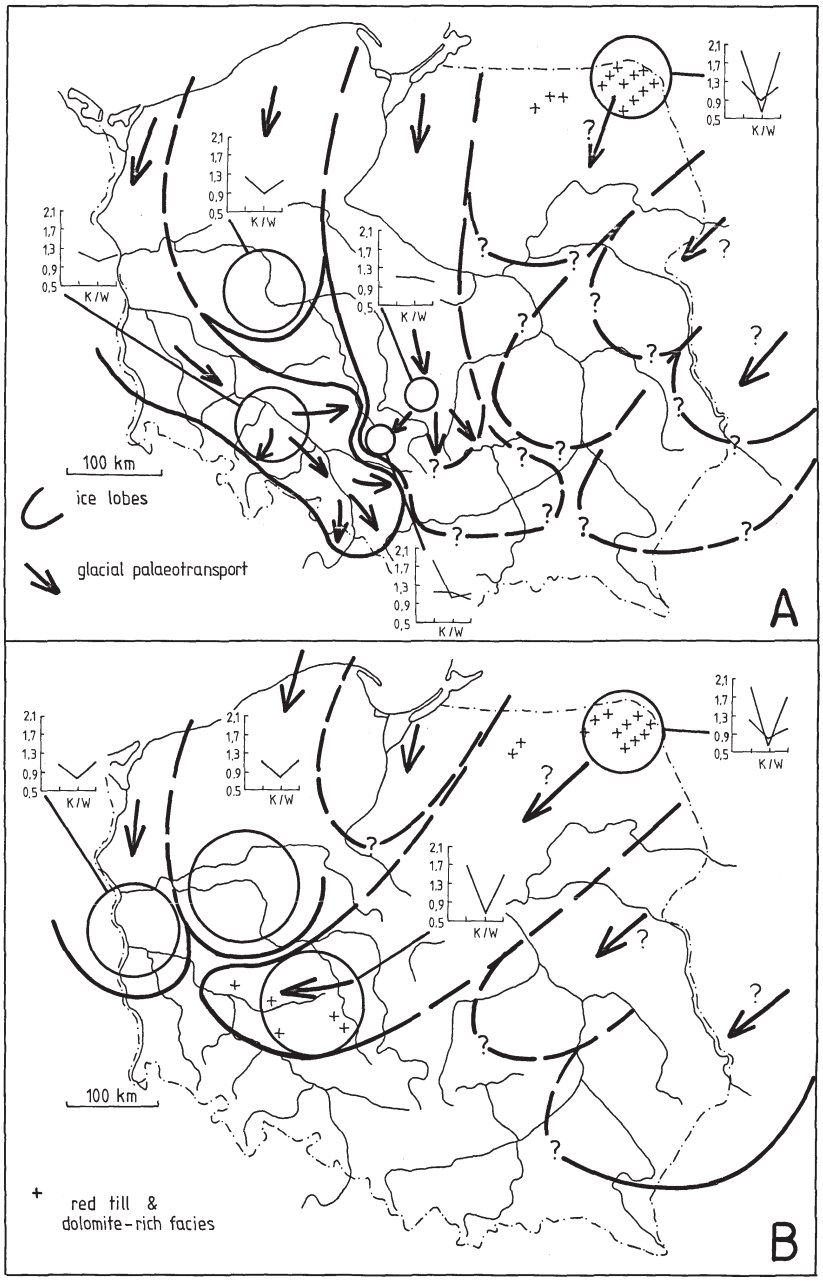


Fig. 8. Palaeogeography of Poland during the late Elsterian Glaciation: Sanian 1 Glaciation (A) – advance of western lobes to their maximal extents; Sanian 2 Glaciation (B) – retreat of western lobes and advance of the eastern lobes to their maximal extents. See text for detailed discussion and comments on till petrography in particular glacial lobes

Carpathian margin. Tills left by the last lobe were documented best from the Bełchatów mine (a younger till of the Kuców Formation), and show equal proportions between Palaeozoic limestones and crystalline rocks (K/W 0.9–1.1; Czerwonka & Krzyszkowski, 1992b). At the same time, glacial lobes in eastern Poland, provisionally called here the north-eastern and eastern lobes, were probably of limited extent, and deposited tills of the East-Baltic lithotypes (Czerwonka & Krzyszkowski, 1995; Krzyszkowski & Czerwonka, 2007) (Fig. 8A).

In the late phase of the glaciation, the Odra and Vistula-Nida lobes retreated considerably, and the Warta-Prosna lobe probably underwent a minor recession (Fig. 8B). It seems likely that all three western lobes deposited the Witosław Till. Retreat of the western lobes made possible advance of the north-eastern lobe up to the Barycz River valley, where tills of the Borowiec type occur. The lobe embraced in part the area of former ice-free "oasis" situated between the Odra and Warta-Prosna lobes (what explains immediate occurrence of the Borowiec-type till upon older tills of the Krzesinki type), and partly the area of the former Odra lobe, where tills of the Wierzbno and Borowiec types were found in the same area or in superposition, like in Blizocin borehole log. The eastern lobe could have advanced in the same time to its maximal extent, to the Carpathian margin (Fig. 8B).

The above extrapolation explains the present-day occurrence of the Borowiec-type tills, and particularly their top dolomite facies, and strange position between the Wierzbno and Witosław tills. It also links genetically red tills of the Elsterian glaciation in north-eastern and western Poland. If this speculative interpretation is true, it anticipates the following palaeogeographic facts:

1. The ice sheet of the younger stadial of the South-Polish Complex glaciations had well-developed lobes of strongly differentiated dynamics.

2. During the younger glaciation (Sanian 2) of the South-Polish Complex, western lobes advanced to their maximal extent earlier than the eastern ones.

3. A large area (*ca*. 25–50 km wide and 100–200 km long) free of ice in this phase of glaciation (intra-ice "oasis") could have existed between the Odra and Warta-Prosna lobes.

4. In the late phase of the glaciation, during general recession of the western lobes, the eastern lobes were more active and increased their extents by 100–250 km. For the north-eastern lobe, such an advance is anticipated by tills of the Borowiec type (and their East-Baltic lithotypes, together with red tills) also in middle Poland, between the Prosna and Vistula river valleys (Fig. 8B).

5. It is likely that the red tills/dolomite-rich tills facies occurs in belts arranged parallel to the transport directions in distal parts of ice lobes (Czerwonka & Krzyszkowski, 1995; Krzyszkowski & Czerwonka, 2007), while in their marginal (proximal) parts this facies tends to be confined to the top of till sections (Ehlers, 1992).

All these palaeogeographic conclusions should be carefully tested, particularly on materials obtained from central and eastern Poland.

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