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Lithostratigraphy and genesis of Quaternary strata between Lanckorona and Myślenice in the Western Outer Carpathians

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The region between the Wieliczka Foothills and the Beskid Makowski Mts. has yielded new data on the accumulation of loess-like deposits during the Vistulian Glaciation. The grain-size distibution and the heavy mineral composition, particularly the significant presence of amphiboles, indicates on aeolian origin for these silty deposits. The silt was most probably derived from glaciofluvial deposits in the Carpathian forelands. Among the Quaternary deposits which accumulated during the Vistulian Glaciation and Holocene, three horizons of loess-like deposits (correlated with the lower, middle and upper younger loesses of the Lublin Upland), three horizons of solifluction deposits, and three horizons of deluvial deposits were distinguished. The accumulation of seven alluvial successions in the Raba and Harbutówka River valleys encompasses a large part of the Quaternary — from the South Polish Glaciations (terraces VII and VI) up to the Holocene (terraces II and I). The lithostratigraphy of the slope deposits (solifluctional and deluvial) and loess-like deposits has been estabilished mainly on the basis of ^{14}C dates of the palaeosol horizons. One of these dates, combined with palynological analysis, confirmed the existence of a warmer period in the Denekamp Interstadial (31 200 ± 1000 years BP in the Harbutowice-1 section). The dates obtained from the Jastrzębia-1 (20 760 ± 300 years BP) and Polanka-1 (20 980 ± 310 years BP and 14 510 ± 150 years BP) sections point to periods favouring the development of soils in the younger and terminal parts of the Younger Pleniglacial. These results, consistent with the dates obtained by other investigators, point to the existence of a warmer period (between 24–20 ka BP) in southern Poland during the maximum development of the ice sheet (Main Stadial) during the last glaciation in northern Poland.

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Key words: Western Carpathian Foothills, Younger Pleistocene, lithostratigraphy, palaeosols.

INTRODUCTION

Studies of the origin and stratigraphy of Quaternary deposits in the Western Outer Carpathians and their foothills have a long history (Klimaszewski, 1948, 1967; Środoń, 1952; Sobolewska *et al*., 1964; Starkel, 1965; Mamakowa and Starkel, 1974, 1977; Wójcik, 1986; Zuchiewicz, 1990; Grzybowski and Bińka, 1994). Researches on the stratigraphy of alluvial deposits in the Skawa (Bober *et al*., 1980; Grzybowski, 1999), Koszarawa (Wójcik, 1989), Dunajec (Zuchiewicz, 1990, 1992), Soła (Alexandrowicz, 1991) and Raba River valleys (Wójcik and Rączkowski, 1994; Paul *et al*., 1996) supported the concept that higher alluvial terraces with accumulated during glacial periods. On the basis of palaeobotanic and TL and ^{14}C results (Butrym and Zuchiewicz, 1985; Grzybowski and Bińka, 1997) the stratigraphy of alluvial deposits in the Carpathian river valleys has been established. Accumulation of loesses and loess-like deposits on the Carpathians foothills was connected with the Middle Polish Glaciations and Vistulian Glaciation periods (Cegła, 1961; Malicki, 1967). The aeolian origin of these deposits was confirmed by heavy mineral analyses, which indicated the presence of amphiboles, pyroxenes and biotite, minerals evidencing longer transport (Sobolewska *et al*., 1964; Maruszczak, 1976; Butrym and Zuchiewicz, 1985; Alexandrowicz, 1991; Grabowski, 1999; Grzybowski, 2001). This paper presents results of grain-size and heavy minerals analyses and their importance for interpretation of the origin of the Quaternary deposits. The detailed lithostratigraphy of the Quaternary deposits covering part of the Wieliczka Foothills was determined on the basis of ^{14}C datings of palaeosoil horizons and palynological analyses.

LOCATION OF THE STUDY AREA

The study area (122.5 km^2) is located in Southern Poland (Fig. 1), at the boundary between the Western Beskidy Foot-

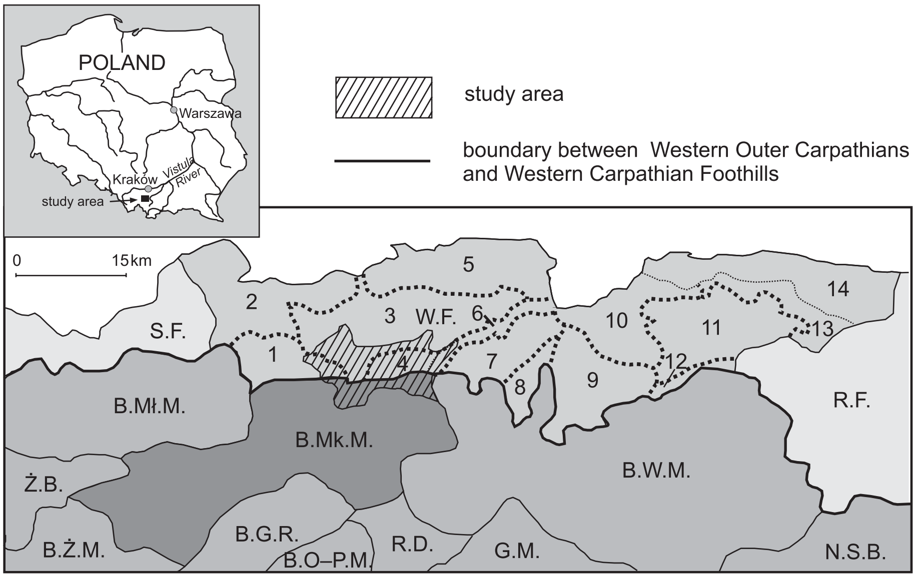


Fig.1 Location of the study area

Western Carpathian Foothills: mesoregions: W.F. — Wieliczka Foothills, S.F. — Silesian Foothills, R.F. — Rożnów Foothills; Wieliczka Foothills microregions (according to German, 1992): 1 — Lanckorona Hills, 2 — Witanowice Foothills, 3 — Głogoczów Foothills, 4 — Barnasiówka Range, 5 — Świątniki Foothills, 6 — Raba River valley, 7 — Dobczyce Foothills, 8 — Wiśniowa Valley, 9 — Szczyrzyc Foothills, 10 — Łapanów Foothills, 11 — Lipnica Foothills, 12 — Żegocina Depression, 13 — Uszew Depression, 14 — Okocim Foothills; Western Outer Carpathians (according to Kondracki, 1998): B.Mk.M. — Beskid Makowski Mountains, Ż.B. — Żywiec Basin, B.Ż.M. — Beskid Żywiecki Mountains, B.MŁ.M. — Beskid Mały Mountains, B.G.R. — Babia Góra Range, B.O–P.M. — Beskid Orawsko-Podhalański Mountains, R.D. — Rabka Depression, B.W.M. — Beskid Wyspowy Mountains, G.M. — Gorce Mountains, N.S.B. — Nowy Sącz Basin

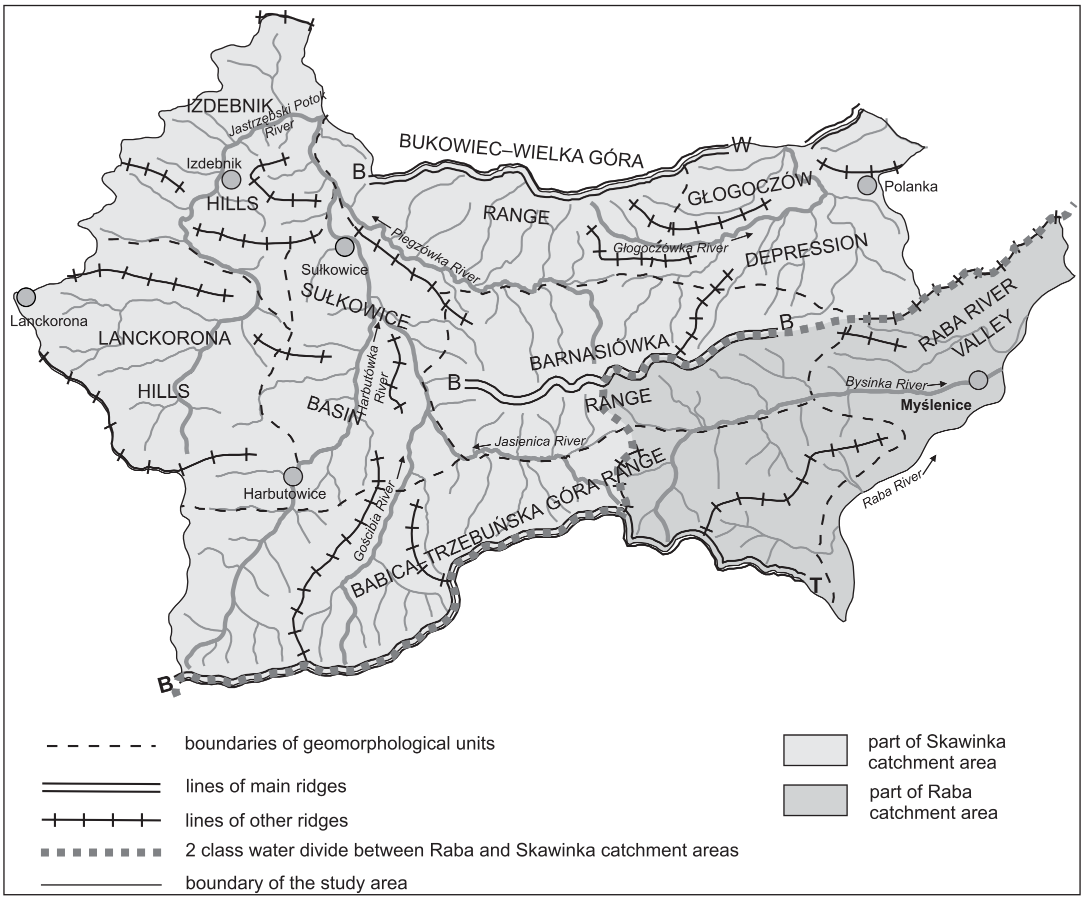


Fig. 2. Geomorphological units and the main landforms of the study area

Main ridges: B–W — Bukowiec–Wielka Góra, B–B – Barnasiówka, B–T — Babica–Trzebuńska Góra

hills and the Western Beskidy Mts. (Kondracki, 1998). The northern and central part of this area belongs to the Wieliczka Foothills, the boundaries of which have been adopted after German (1992). The southern part is situated in the Beskid Makowski Mts. (Kondracki, 1998).

GEOMORPHOLOGICAL UNITS OF THE STUDY AREA AND THEIR MORPHOLOGY

The diverse morphology of the study area reflects its location at the boundary between the foothills and the Beskidy Mts.

Eight geomorphologic units, referred to below as regions (Fig. 2), have been distinguished on the basis of different morphological forms and underlying flysch lithologies as well as by comparison with the sub-division of German (1992).

Three main E–W orientated ranges: Bukowiec–Wielka Góra (in the north), Barnasiówka (in the central part) and Babica–Trzebuńska Góra (in the south) are separated by the longitudinal valleys of the Piegzówka, Głogoczówka, Jasienica and Bysinka rivers. These ranges are truncated by the transverse Harbutówka and Raba River valleys. The Harbutówka River with its tributary (Gościbia) subdivide the area studied into western and eastern parts. The rivers and streams draining the area discharge waters from two catchment areas: the Skawinka and Raba. A fragment of a 2 class watershed between these two catchment areas is located in the southeastern part of the area (Fig. 2).

GEOLOGICAL SETTING

The study area includes exposures of flysch rocks representing the Sub-Silesian, Silesian and Magura nappes (Książkiewicz, 1953; Wójcik and Rączkowski, 1994).

Rocks of the Sub-Silesian Nappe, strongly folded and displaced, are exposed in four small tectonic windows: Lanckorona–Jastrzębia, Sułkowice, Harbutowice–Jasienica, and Myślenice, located in front of the Magura thrust (Figs. 3 and 4). Thirteen, mainly silty-marly lithostratigraphic members are exposed within this succession in the study area.

Rocks of the Silesian Nappe are exposed in the northern and central part of the study area (Fig. 3), forming three anticlines: Zebrzydowice–Izdebnik–Rudnik, Jawornik (Fig. 4), and Borzęta, separated by faults and two thrust slices: Podchybie–Biertowice and Stroń–Pasieka. The strike of beds is strongly variable, nevertheless a E–W orientation prevails. Within the study area, nineteen members belonging to this unit are exposed: from the Cieszyn Limestones (Jurassic/Cretaceous) to the Krosno Beds (Oligocene). The widest lateral range is observed in the case of the Lower and Upper Istebna Beds, which occur in the northern part of the area studied.

Strata of the Magura Nappe are exposed in the southern part of the area (Fig. 3), and form two structures, the marginal thrust slice, and the Budzów–Zagórna Anticline (Fig. 4), sub-parallel to it. These structures are cut by two large faults. Eight lithostratigraphic members showing an orientation close to E–W, from the oldest Ropianka Beds (Senonian-Palaeocene) to the youngest Supra-Magura Beds (Upper Eocene and Oligocene), are exposed within this succession. The widest lateral extent is observed in the case of the Magura Beds, which build most of the Babica–Trzebuńska Góra Range.

ORIGIN AND STRATIGRAPHY OF QUATERNARY DEPOSITS AND THE MAXIMUM RANGE OF THE SOUTH POLISH GLACIATIONS IN AREA: STATE OF RESEARCH

Detailed investigations of Quaternary strata at the Wieliczka Foothills/Beskid Makowski Mts. boundary between Lanckorona and Myślenice have not been carried out on a larger scale. Outcrop patterns are shown on three maps (Sucha Beskidzka, Osielec and Myślenice) of the Detailed Geological Map of Poland at a 1:50 000 scale, and the Wadowice sheet of the Geological Map of Poland at 1:50 000

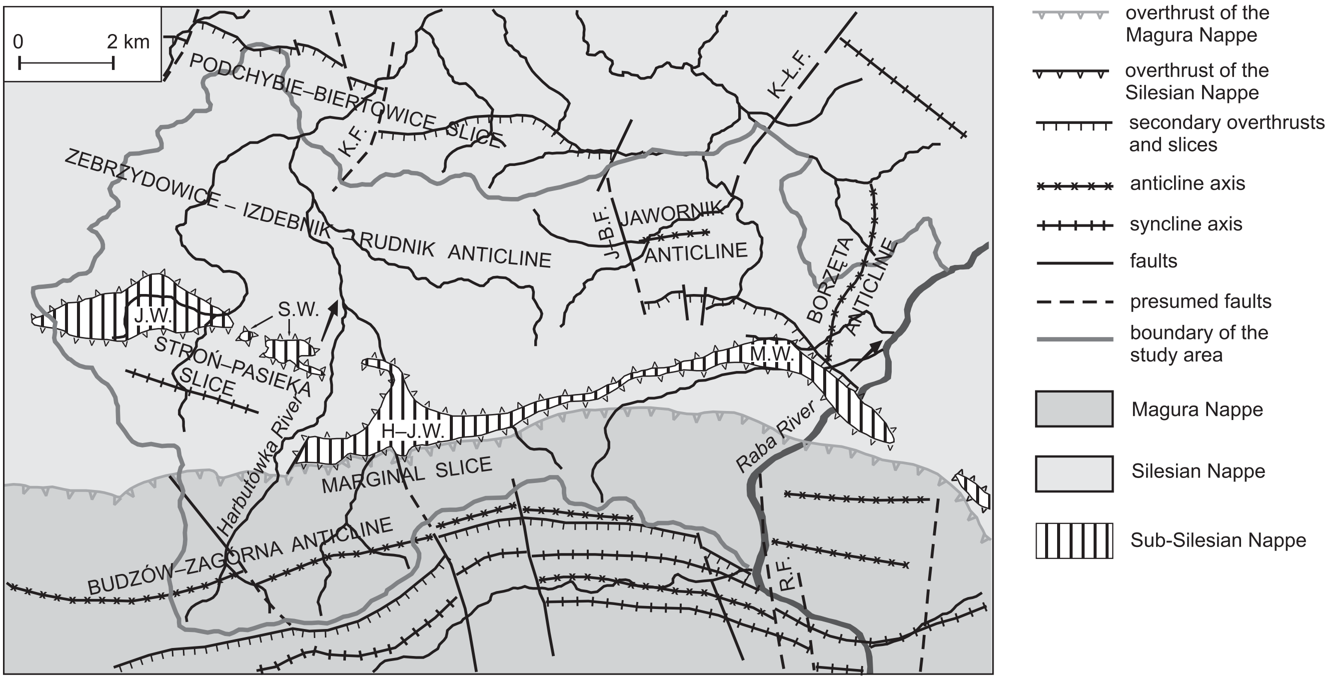


Fig. 3. Tectonic sketch of the study area (according to Rączkowski and Wójcik, 1994; Paul and Ryłko, 1996)

Tectonic windows: J.W. — Jastrzębia, S.W. — Sułkowice, H–J.W. — Harbutowice–Jasienica, M.W. — Myślenice; faults: K.F. — Krzywaczka, J–B.F. — Jawornik–Bugaj, K–Ł.F. — Krzyszkowice–Łyczany, R.F. — Raba

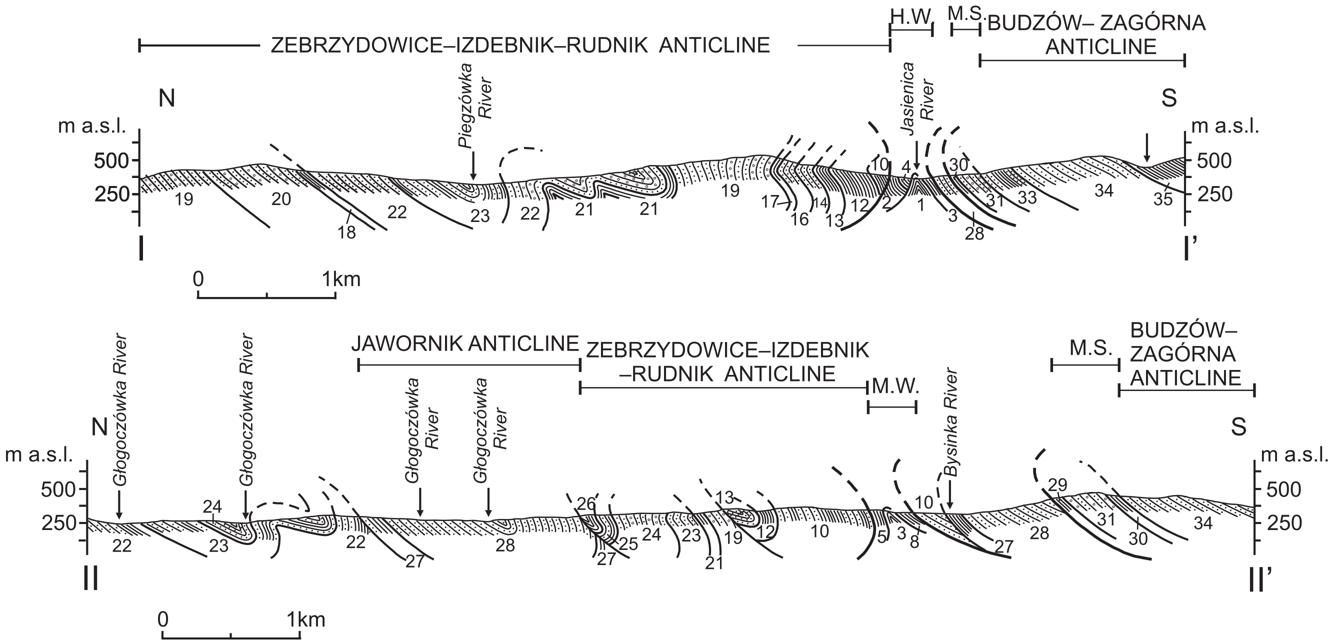


Fig. 4. Geological cross-sections (I–I' and II–II') through the Sub-Silesian, Silesian and Magura series

Sub-Silesian series: 1 — Vervovice Beds, 2 — Godula Beds, variegated shales, 3 — Jasienica Marls, 4 — Żegocina Marls, 5 — Węglówka Variegated Marls, 6 – shales, variegated marls and glauconite sandstones, 7 — Hieroglyphic Beds, 8 — Menilite Beds; **Silesian series**: 9 — Cieszyn Limestones, 10 — Upper Cieszyn Shales, 11 — Grodziszcze Sandstones, 12 — Vervovice Beds (Vervovice Shales), 13 — Lower Lgota Beds, 14 — Middle Lgota Beds, 15 — Barwałd Beds, 16 — Upper Lgota Beds: cherts, hornstones and sandstones, 17 — Jaspis Beds, 18 — Godula Beds, variegated shales, 19 — Godula Beds, thick-bedded sandstones, 20 — Godula Beds, sandstones and shales, 21 — Istebna Beds, variegated shales, 22 — Lower Istebna Beds, 23 — Upper Istebna Beds, lower shales, 24 — Upper Istebna Beds, sandstones and conglomerates, 25 — Upper Istebna Beds, upper shales, 26 — variegated shales, 27 — Menilite Beds, 28 — Krosno Beds; **Magura series**: 29 — Ropianka (Inoceramian) Beds, 30 — variegated shales, 31 — Ciężkowice Beds, 32 — Upper Pasierbiec Beds, 33 — Submagura Beds (Zembrzyce Shales), 34 — Magura Beds, 35 — Supra-Magura Beds (Budzów Shales); **tectonic units**: H. W. — Harbutowice–Jasienica Tectonic Window, M. W. — Myślenice Tectonic window, M. S. — marginal slice

scale (Książkiewicz, 1951, 1953), whereas the only exposure of Quaternary strata in the "Myślenice" brickyard, described and analysed in detail by Klimaszewski (1948) and Cegła and Starkel (1967), no longer exists.

Klimaszewski (1948, 1967) distinguished alluvia of four terraces in the Raba River valley. According to him, alluvia of the highest terrace (I: 16–30 m) accumulated during the South Polish Glaciations; alluvia of terrace II (5–12 m), locally covered with loess, accumulated during the Middle Polish Glaciations; alluvia of terrace III (2–6 m) were deposits during the Vistulian Glaciation, whereas alluvia of the flood-plain terrace accumulated during the Holocene.

Klimaszewski (1948) described for the first time the succession of slope deposits overlying gravels of the upper terrace of the Raba River, exposed in the "Myślenice" brickyard. Later investigations by Cegła and Starkel (1967) helped to reconstruct the origin and stratigraphy of the slope and alluvial deposits in this exposure and their correlation with slope deposits at Wadowice (Sobolewska *et al*., 1964). The possibility of an aeolian (loess) origin for the silty deposits occurring in the upper part of the succession, interpreted by Klimaszewski (1948) as slopewash, has also been proposed (Cegła and Starkel, 1967).

The most recent mapping covering almost the entire study area, was presented on the Myślenice (Paul *et al*., 1996) and Osielec sheets (Wójcik and Rączkowski, 1994) of the Detailed Geological Map of Poland at a scale of 1:50 000. Alluvia from the South Polish (Elsterian; one horizon), Middle Polish (Saalian; one horizon — Wójcik and Rączkowski, 1994; two horizons — Paul *et al*., 1996), and Vistulian (Weichselian) glaciations (one horizon), as well as from the Holocene (three horizons) have been distinguished. Most of the Raba River alluvia, distinguished by Klimaszewski (1948) as horizon II, dating from the Middle Polish Glaciations, are, in the light of new data, considered to represent younger alluvia (Vistulian). The age of late glacial and Holocene alluvia has been confirmed by TL and ^{14}C datings (Rutkowski, 1984, 1993). The recognised slope deposits include colluvia and congeliflunctional-deluvial deposits, the presence of which was connected with the Last Glacial and the Holocene. Loess-like deposits (distinguished in the vicinity of Myślenice), depositsed during the Vistulian Glaciation, have not been documented by grain-size and heavy mineral content analysis (Wójcik and Rączkowski, 1994; Paul *et al*., 1996).

Glacial deposits are not present in the area, though rare Scandinavian erratic boulders, remnants of glacial or fluvioglacial deposits, have been encountered (Klimaszewski, 1936, 1948; Sokołowski, 1952; Dudziak, 1961). The presence of erratic boulders and geomorphological criteria allow one to determine the maximum ice sheet extent (Klimaszewski, 1948; Sokołowski, 1952) in the study area (Fig. 5). Later investigations (Dudziak, 1961; Wójcik and Rączkowski, 1994; Paul *et al*., 1996) did not confirm such a great extent of the ice sheet; weathered erratics were observed only at the northern margin of the study area, in the region of Izdebnik and Głogoczów at 300–350 m a.s.l. (Fig. 5).

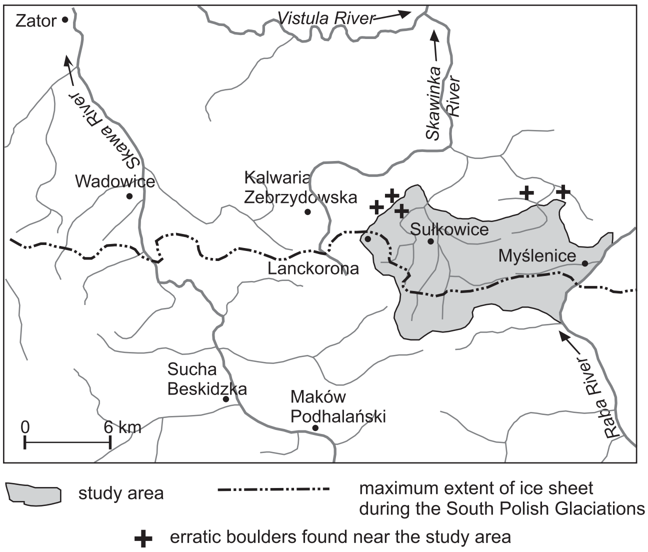


Fig. 5. Maximum extent of ice sheet of the South Polish Glaciations on the Wieliczka Foothills between Wadowice and Myślenice (according to Sokołowski, 1952)

ORIGIN OF QUATERNARY DEPOSITS IN SELECTED AREAS OF THE WIELICZKA FOOTHILLS

Detailed analysis of Quaternary deposits have been carried out in several sections located in the Sułkowice Basin, at the Lanckorona and Izdebnik Hills boundary, in the Głogoczów Depression, and in the Raba River valley (Fig. 6). The origin of Quaternary deposits has been determined on the basis of laboratory analyses, including: grain-size, heavy minerals (Tables 3 and 4), $CaCO_3$ content, selected grain-size parameters (Tables 1 and 2), and the geological and geomorphological setting of these deposits, shown on geological cross-sections. The analysis of heavy minerals carried out on the 0.063–0.1 mm fraction by Dr. Bogusław Bagiński (Institute of Mineralogy and Petrology, Warsaw Univ.) was crucial for determination of the origin of the loess-like deposits. The analysis indicated the presence of minerals (particularly amphiboles) allogenic for the Carpathian flysch rocks (Chlebowski, 1988), as well as small quantities of disthene, andalusite, sillimanite and epidote (characteristic of only some flysch unit). In turn, the content of heavy minerals from the flysch rocks (Magura, Sub-Magura, Inoceramian, Krosno and Istebna Beds; Szczurowska, 1973, 1975, 1976) included only zircons, tourmaline, garnets, and titanium minerals (mainly rutile) and, in rare cases, also glauconite and staurolite (fraction <0.1 mm). In all analysed fractions of the flysch rocks, no amphiboles, sillimanite, andalusite, disthene or epidote were observed. According to the most detailed mineralogical studies (Krysowska-Iwaszkiewicz and Unrug, 1967) these minerals are missing from the Sub-Silesian, Silesian and Magura Series of the Western Outer Carpathians. Thus, the presence of these minerals in Quaternary strata unequivocally indicates long transport (Sobolewska *et al.*, 1964; Grzybowski, 2001), either by

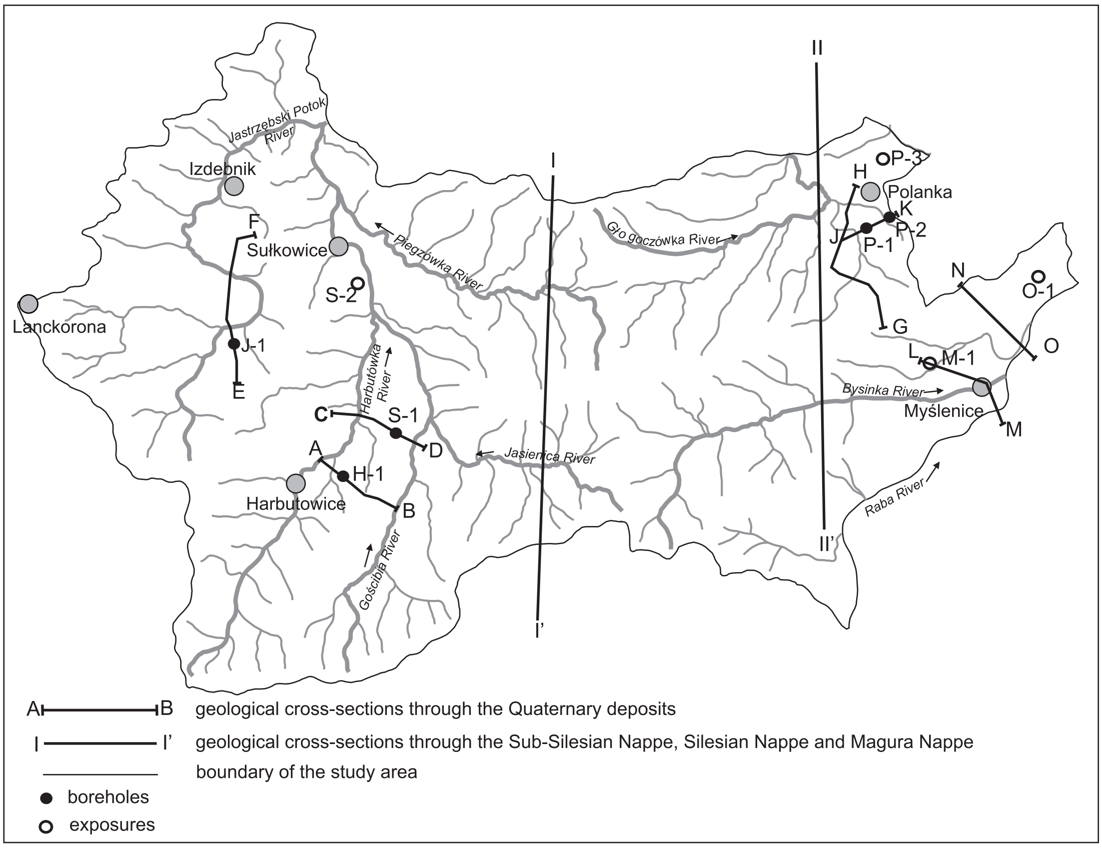


Fig. 6. Location sketch of cross-sections, boreholes and exposures

Boreholes: H-1 — Harbutowice-1, J-1 — Jastrzębia-1, P-1 — Polanka-1, P-2 — Polanka-2, S-1 — Sułkowice-1; exposures: M-1 — Myślenice-1, O-1 — Osieczany-1, P-3 — Polanka-3, S-2 — Sułkowice-2

Table 1

Grain-size parameters (according to Folk and Ward, 1957) and loess index (according to Nowak, 1981) of the Quaternary deposits from sections: Harbutowice-1, Sułkowice-1, Sułkowice-2 and Jastrzębia-1

Lithological units (number of sample) [depth]	M_z [φ] mean grain diameter	σ_I standard deviation	Sk_I skewness	K_G curtosis	L loess index (average)
Harbutowice-1 section					
j [0.0–1.5 m]	6.19–6.88	2.27–3.04	0.14–0.51	1.22–1.34	1.29–1.77 (1.58)
h [1.5–4.1 m]	6.93–8.58	4.15–4.21	–0.17–0.04	0.72–0.80	0.30–0.56 (0.44)
g [4.1–5.0 m]	8.09–8.30	3.68–4.06	0.02–0.08	0.85–0.91	0.41–0.73 (0.57)
f [5.0–7.5 m]	8.29–8.59	3.16–3.38	0.05–0.07	0.78	2.10–2.43 (2.26)
e [7.5–9.7 m]	7.23–7.60	2.77–3.18	0.48–0.57	0.85–1.08	2.85–4.93 (3.54)
d [9.7–12.3 m]	6.25–7.12	2.26–3.40	0.55–0.68	1.34–1.91	2.63–4.33 (3.31)
c [12.3–13.1 m]	3.00–5.07	3.81–4.74	0.10–0.28	0.82–1.08	0.12–0.44 (0.28)
b [13.1–13.5 m]	7.14–7.18	2.94–3.01	0.50–0.55	1.25–1.31	2.55–3.10 (2.83)
a [13.5–14.0 m]	4.80–5.76	4.43–5.36	–0.11–0.07	1.25–1.37	0.57–0.60 (0.585)
weathered deposit from the Barwałd Sandstones (cross-section A–B, H-2 section)					
[0.4–0.6 m]	3.84	5.02	–0.11	0.64	0.11
Sułkowice-1 section					
e [0.0–1.5 m]	6.76–7.16	2.51–3.26	0.26–0.48	0.81–0.96	2.04–2.54
d [1.5–2.2 m]	6.99	2.25	0.11	0.77	2.05
c [2.2–4.0 m]	7.67–8.0	2.42–3.72	0.23–0.53	0.77–0.86	2.95–3.61 (3.40)
b [4.0–5.3 m]	6.88–7.23	2.29–3.13	0.42–0.60	0.72–1.14	3.60–4.60 (3.94)
a [5.3–5.6 m]	6.64	3.73	0.27	1.28	1.28
Sułkowice-2 section					
d (7) [0.0–1.75 m]	7.15	3.08	0.60	1.50	4.53
d (6) [0.0–1.75 m]	7.87	3.07	0.45	0.90	3.73
c (5) [1.75–2.75 m]	8.03	2.95	0.13	0.82	1.19
c (4) [1.75–2.75 m]	2.94	2.77	0.65	2.29	0.04
c (3) [1.75–2.75 m]	7.97	2.46	0.08	0.81	3.22
b (2) [2.75–3.0 m]	7.71	2.49	0.05	0.82	1.93
a (1) [3.0–3.5 m]	7.31	1.99	0.05	0.87	2.31
Jastrzębia-1 section					
f [0.0–1.6 m]	6.94–7.31	2.66–3.13	0.54–0.56	1.16–1.39	2.61–2.86 (2.73)
e [1.6–2.0 m]	7.69	3.21	0.53	0.91	1.71
d [2.0–4.2 m]	6.82–7.20	2.50–2.91	0.43–0.62	1.15–1.61	2.15–3.79 (3.16)
c [4.2–6.7 m]	6.66–6.93	1.86–2.51	0.34–0.53	1.06–1.39	3.05–5.00 (3.90)

H-2 — Harbutowice-2 section

Table 2

Grain-size parameters (according to Folk and Ward, 1957) and loess index (according to Nowak, 1981) of the Quaternary deposits from other sections of the Sułkowice Basin

Quaternary deposits	M_z [φ] mean grain diameter	σ_I standard deviation	Sk_I skewness	K_G curtosis	L loess index
ls3	6.62–7.30	2.51–3.26	0.26–0.59	0.81–1.28	1.59–3.03
s3	4.44–8.68	2.73–5.01	–0.18–0.30	0.72–1.19	0.13–1.77
d1	8.33–8.87	3.46–4.55	0.09–0.28	0.73–1.00	0.50–2.06
ls2	6.68–7.39	2.22–3.06	0.32–0.54	0.94–1.25	2.28–5.38
ls1	6.39	1.87	0.36	1.19	3.25
w	6.64–9.09	2.95–3.95	–0.30–0.47	0.80–1.28	0.72–1.91

w — weathered deposits, ls1 — lower loess-like deposits, ls2 — middle loess-like deposits, d1 — lower deluvial deposits, s3 — middle solifluctional deposits, ls3 — upper loess-like deposits

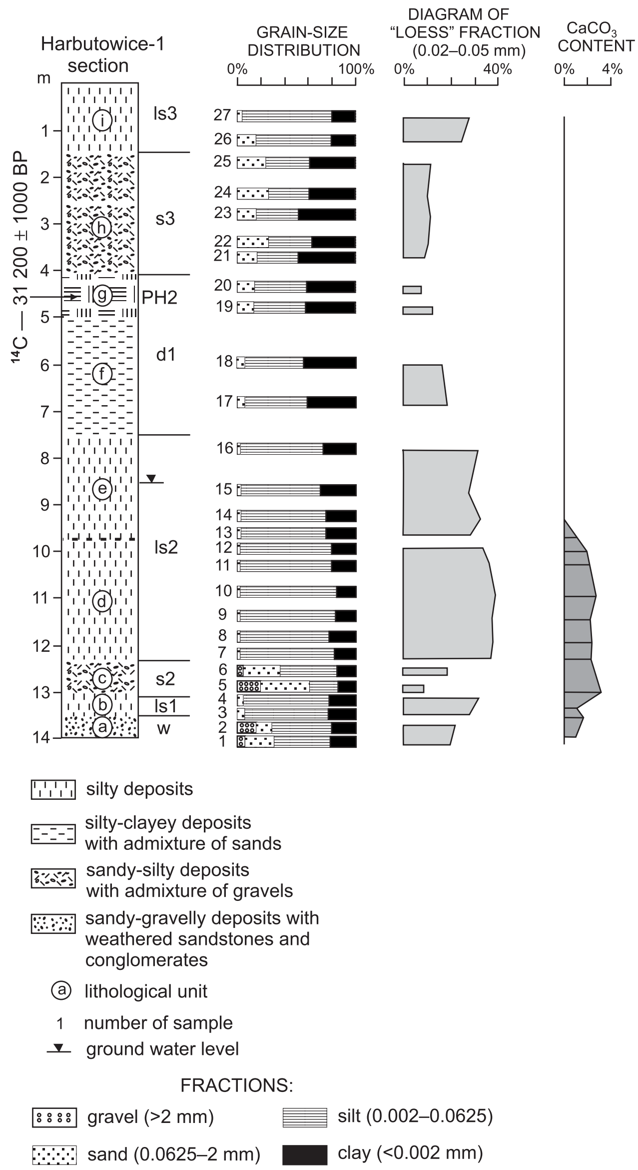


Fig. 7. Harbutowice-1 section

PH2 — palaeosoil horizon; w — weathered deposits; ls1 — lower loess-like deposits; s2 — lower solifluctional deposits; ls2 — middle loess-like deposits; d1 — lower deluvial deposits; s3 — middle solifluctional deposits; ls3 — upper loess-like deposits

Table 3

Composition of heavy minerals of Quaternary deposits from sections of the Sułkowice Basin and Lanckorona Hills

Litholo-gical units (number of sample) [depth]	MINERALS [%]																
	Semi-transparent, opaque		Transparent														
	Fe car-bonates*	Fe and Cr oxides**	total sum	C	R	T	M	Gr	E	St	D+A	Sl	Ap	Ch	Am	B	Gl
Harbutowice-1 section																	
j (27)	11.0	38.0	51.0	2.1	18.0	1.0	0	2.6	2.0	1.0	0	1.0	0	1.3	7.9	14.1	0
j (26)	26.0	39.0	35.0	6.8	8.0	1.9	0	9.4	1.4	1.0	0	0	0	0	0.7	5.8	0
h (22)	62.0	13.5	24.5	0.6	9.7	8.9	0	0	0	0	0	0	0	0	0	5.3	0
g (19)	60.6	29.0	10.4	1.7	2.0	4.6	0	0.9	0	0	0	0	0	0	0.5	0.7	0
f (18)	89.0	6.0	5.0	0.8	2.0	2.2	0	0	0	0	0	0	0	0	0	0	0
f (17)	98.2	1.2	0.6	0	0	0	0.6	0	0	0	0	0	0	0	0	0	0
e (16)	68.0	12.1	19.9	5.8	11.2	0	0	0	0	0	0	0	0	0	1.2	1.7	0
e (14)	18.0	47.9	34.1	2.8	7.5	4.5	0	5.7	0	0	0	0	0	0	2.2	11.4	0
d (11)	24.0	40.5	35.5	11.4	8.0	2.9	0	0	0	0	0	0	0	0	5.9	7.3	0
d (8)	17.2	41.4	41.4	7.8	8.6	4.9	0	3.0	0	0	0	0	0	0	3.1	12.6	1.4
c (6)	51.3	18.4	30.3	7.4	7.6	3.2	0	6.6	0	0	0	0	0	0	1.2	2.2	2.1
b (3)	19.3	43.4	37.3	3.8	14.2	2.0	0	11.4	0	0	0	0	0	0	0	1.9	4.0
a (1)	52.1	16.9	31.0	4.4	6.7	4.5	0	8.4	0	0	0	0	0	0	0	2.1	4.9
weathered deposit from the Barwałd Sandstones (cross-section A–B, H-2 section)																	
[0.5 m]	29.0	39.0	32.0	10.9	8.0	3.6	0	1.5	1.5	0.5	0	0	0	0.7	0	5.3	0
weathered deposit from variegeted shales and marls (cross-section A–B, H-3 section)																	
[1.5 m]	9.2	82.5	8.3	0	6.0	0	0	0	0	0	0	0	0	0	0	2.3	0
[2.5 m]	26.2	64.7	9.1	4.6	2.5	2.0	0	0	0	0	0	0	0	0	0	0	0
Sułkowice-1 section																	
e (10)	90.0	3.4	6.6	1.4	1.0	0.7	0	1.8	0	0	0	0	0	0	0.5	1.2	0
e (9)	0	68.0	32.0	4.5	8.5	2.9	0	4.0	2.7	0	0	0	0	0	5.2	4.2	0
c (7)	23.0	64.0	13.0	3.0	0	2.5	0	0	0	0	0	0	0	0	3.5	4.0	0
b (4)	0	43.0	57.0	5.5	14.5	3.7	0	2.3	2.3	0	0	0	0	0	3.2	25.5	0
b (2)	0	34.0	66.0	4.0	7.0	3.5	0	0	2.0	0	0	0	0	0	2.0	47.5	0
a (1)	70.0	18.5	11.5	1.8	3.0	2.2	0	0.8	0.6	1.5	0	0	0	0	0.5	1.1	0
Sułkowice-2 section																	
d (7)	0	66.0	34.0	2.2	7.0	3.8	0	5.4	2.8	1.9	2.5	0	0	0	6.9	1.5	0
d (6)	0	73.0	27.0	0	7.0	0.9	0	7.0	0	1.8	3.3	0	0	0	2.6	4.4	0
c (3)	0	79.0	21.0	2.0	7.0	0	0	1.2	0	0	0	0	0	0	0	10.8	0
a (1)	0	87.0	13.0	0	9.0	0	0	0	0	0	0	0	0	0	0	4.0	0
Jastrzębia-1 section																	
f (17)	29.0	49.0	22.0	0.9	4.8	1.9	0	4.1	1.4	0	0.8	0	0.3	0	3.2	4.6	0
e (15)	55.0	14.4	30.6	0.9	3.0	3.6	0	11.6	0	0	1.7	0	0	0	3.5	6.3	0
d (13)	53.0	26.3	20.7	0	3.5	2.2	0	6.0	0	0	0	0	0	0	3.9	5.1	0
d (12)	37.0	29.8	33.2	0.8	3.0	3.6	0	8.1	0	1.9	1.6	0	1.7	0	5.3	7.2	0
c (9)	31.0	39.0	30.0	2.5	4.0	3.0	0	15.2	0	1.3	0	0	2.0	0	2.0	0	0
c (7)	51.0	28.4	20.6	2.6	2.0	2.0	0	6.9	0	1.5	0	0	2.0	0	1.2	2.4	0
b (5)	30.0	45.0	25.0	0.7	2.5	2.1	0	9.8	0	0.7	0.8	0	2.1	0	1.4	4.9	0
a (2)	39.0	52.0	9.0	0	3.0	0	0	1.9	0	0	0.9	0	2.0	0	0	1.2	0
upper loess-like deposits (cross-section E–F, J-2 and J-3 sections)																	
J-2 [0.5 m]	0	53.0	47.0	10.7	7.5	6.8	0	5.4	1.2	1.4	0	0	0	0	1.8	12.2	0
J-3 [1.0 m]	2.0	68.0	30.0	1.4	8.0	1.4	0	6.0	0	1.3	2.5	0	0	0	3.4	6.0	0
J-3 [2.5 m]	2.5	71.0	26.5	1.8	6.0	1.3	0	4.5	0	1.9	2.2	0	0	0	3.8	5.0	0

* — mainly siderite and ankerite; ** — chromite, ilmenite, magnetite; resistant minerals: C — zircon, R — rutile, T — tourmaline, M — monazite; moderately resistant minerals: Gr — garnets, E — epidote, St — staurolite, D+A — disthene and andalusite, Sl — sillimanite, Ap — apatite; poorly resistant minerals: Ch — chlorite, Am — amphibole, B — biotite, Gl — glauconite; sections: H-2 — Harbutowice-2, H-3 — Harbutowice-3, J-2 — Jastrzębia-2, J-3 — Jastrzębia-3

Table 4

Composition of heavy minerals of Quaternary deposits from sections of the Głogoczów Depression

Litholo-gical units (number of sample) [depth]	MINERALS [%]												
	Semi-transparent, opaque		Transparent										
	Fe car-bonates*	Fe and Cr oxides**	total sum	C	R	T	Gr	E	St	D+A	Ap	Am	B
Polanka-2 section													
d (6)	15.0	44.0	41.0	1.5	15.0*	1.3	2.7	0.7	1.0	0	0	1.3	17.5
c (4)	17.0	28.0	55.0	0.7	17.0*	3.1	21.0	0	4.0	5.4	0	0.8	3.0
c (3)	2.0	58.0	40.0	1.7	12.0*	0	10.1	0	4.1	0.9	0	0	11.2
b (2)	0	58.9	41.1	3.4	2.5	6.8	11.2	0	6.0	0	0	2.6	8.6
a (1)	0	52.6	47.4	5.3	10.0*	4.1	16.5	0	4.0	0	0.6	1.1	5.8
Polanka-3 section													
c (9)	0	57.0	43.0	2.1	10.0	1.5	4.9	0	3.8	0.9	0	4.3	15.5
c (7)	3.0	60.0	37.0	2.4	6.0	6.2	5.0	0.8	3.7	2.0	1.0	8.5	1.4
c (6)	4.0	57.5	38.5	10.0	7.0	4.0	2.7	0	4.8	2.8	1.0	2.0	4.2
b (5)	0	74.0	26.0	4.1	5.0	4.0	5.3	0	0.8	3.8	0	0.5	2.5
b (4)	3.0	74.0	23.0	1.9	5.0	3.7	2.0	0	4.5	2.6	1.0	1.3	1.0
a (2)	2.0	90.0	8.0	0	0	2.0	0	0	0	0	0	0	6.0
upper loess-like deposits (cross-section G–H, M-1 and M-2 sections)													
M-1 [0.8 m]	0	37.5	62.5	1.5	26.0*	1.0	6.5	1.5	1.5	0	2.5	9.0	13.0
M-1 [1.8 m]	0	43.0	57.0	0.6	21.0*	3.0	21.0	0	2.4	3.0	0	1.8	4.2
M-2 [1.0 m]	56.0	22.0	22.0	0.8	2.0	4.4	5.8	0	0.7	3.7	1.7	2.9	0
M-2 [2.5 m]	66.0	20.0	14.0	0	2.0	2.3	3.1	0	0.8	3.3	0	1.5	1.0
middle deluvial deposits (cross-section G–H, M-1 section)													
M-1 [2.8 m]	34.8	26.0	39.2	1.7	4.5	0	4.3	0	0	0	0	3.5	25.2
M-1 [3.4 m]	45.0	44.0	11.0	2.2	2.5	1.4	3.6	0	0.6	0	0	0	0.7
middle loess-like deposits (cross-section G–H, M-2 and M-3 sections)													
M-2 [4.2 m]	45.0	31.0	24.0	1.0	2.0	0	0	0	0	2.0	0	1.0	18.0
M-3 [3.0 m]	25.0	40.7	34.3	1.8	3.0	4.7	7.5	0	0	0.8	0.7	3.7	12.1
M-3 [4.2 m]	0	39.0	61.0	0	16.0*	4.3	29.5	0	4.5	1.8	0	1.9	3.0
M-3 [5.4 m]	7.5	36.0	56.5	0	5.8	1.9	44.0	0	3.2	1.6	0	0	0
alluvia of terrace I (cross-section G–H, M-4 section)													
M-4 [1.9 m]	4.0	62.0	34.0	6.2	9.0	2.7	7.0	0	3.5	2.8	0	1.8	1.0

(R)* — rutile together with semi-transparent oxides; sections: M-1 — Myślenice-1, M-2 — Myślenice-2, M-3 — Myślenice-3, M-4 — Myślenice-4; other explanations as in Table 3

means of water or wind. Palaeogeographic studies of the Polish Carpathians (Starkel, 1972) suggest that the source of amphiboles might be glaciofluvial deposits of Scandinavian orgin, covering the Carpathian forelands. Therefore, silty clays characterised by a large content of the silty fraction (>60%), and within it, of the "loess" fraction (>20%), a small content of the sand and gravel fraction (typically <5%), a high value of the loess index (Nowak, 1981), and the presence of amphiboles within the heavy mineral fraction, are considered to represent loess-like deposits.

LITHOSTRATIGRAPHIC SECTIONS OF SELECTED BOREHOLES AND EXPOSURES IN THE SUŁKOWICE BASIN

In the lithostratigraphic section of the Harbutowice-1 borehole (H-1), located between the valleys of the Harbutówka and Gościbia rivers (Fig. 6), nine lithological units (a–j) of a total thickness of 14 m (Fig. 7) were distinguished (Grabowski, 1999). This succession is the most complete of all analysed Quaternary successions in the area, including three units of loess-like deposits separated by solifluctional and deluvial sediments. Pollen analysis (Grabowski, 1999) of a part of the H-1 section (4–14 m) made by Dr. Krzysztof Bińka (Institute of Geology, Warsaw Univ.), showed two cooler (accumulation of units b, e — NAP content *ca.* 80–90%) and two warmer intervals (accumulation of units d, g — AP content up to 45%). Unit a is considered to represent weathered deposits (w) of glauconitic sandstones from the Barwałd Beds. Unit b, with a considerable silt content and a heavy mineral content similar to that of unit a (Table 3), represents the lower loess-like deposits (ls1). Due to the small thickness of these deposits (0.4 m) and the activity of slope processes during their accumulation, the heavy mineral content in deposits of units a–c is very similar (Table 3); the lack of amphiboles indicating short transport. Sandy-silty clays of unit c (thickness 0.7 m), with the grain-size and heavy mineral content (Table 3) very similar to the weathered deposits of unit a, represent the lower solifluctional deposits (s2). Deposits of units d and e (thickness up to 5 m), are considered to represent the middle loess-like deposits (ls2), due to the largest content of silt, of $CaCO_3$ of loess-origin, and particularly of amphiboles (Table 3). Accumulation of the younger part of these deposits took place in cooler climatic conditions, as did the accumulation of the lower loess-like deposits. The upper part of the loess-like deposits of unit e (1.5 m thick) is devoid of $CaCO_3$, most probably due to decalcificiation. Deposits from units f and g, 3.4 m thick, and characterised by a large silt content a considerable sand content and a small content of the "loess" fraction, these being different grain-size indicators in comparison to those determined for the loess-like deposits (Table 1) and deficient in heavy minerals (Table 3), represent the lower deluvial deposits (d1), which originated due to slopewash of weathered deposits of the

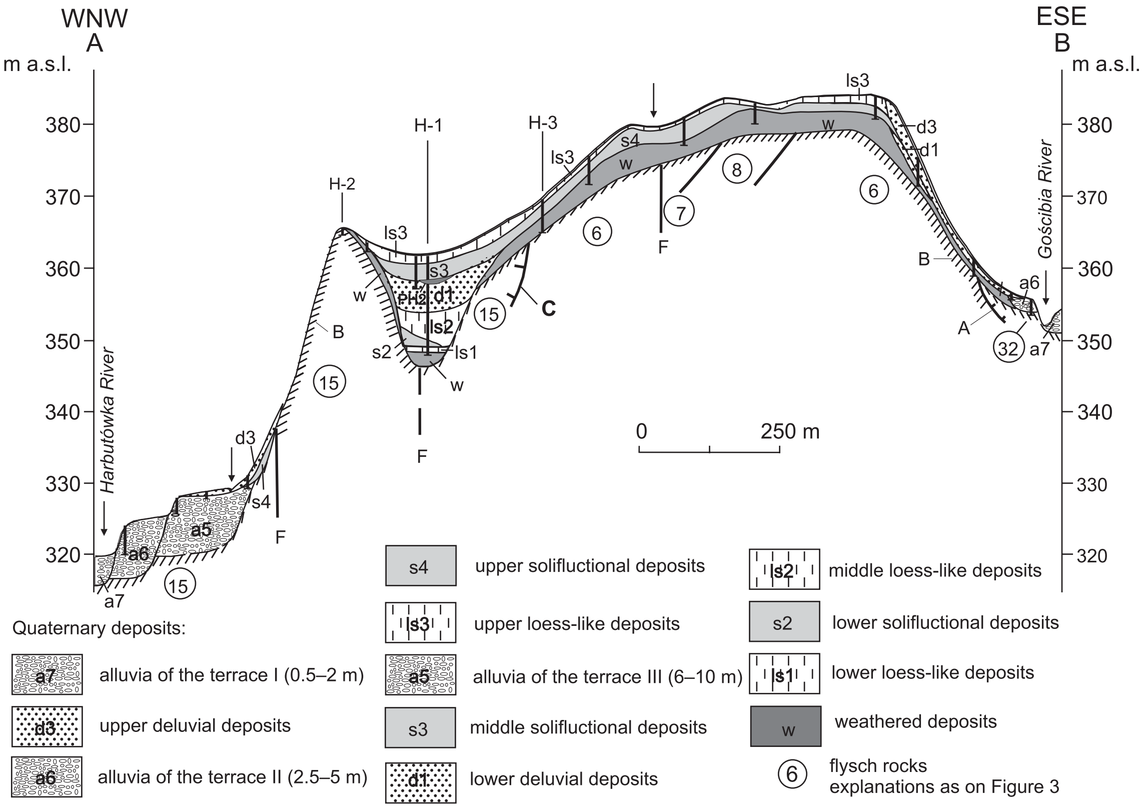


Fig. 8. Geological cross-section A–B through the southern part of the Sułkowice Basin

H-1 to H-3 — Harbutowice boreholes; A — overthrust of the Magura series over the Sub-Silesian series; B — bedrock; C — overthrust of the Silesian series over the Sub-Silesian series; F — faults; PH2 — palaeosoil horizon

Upper Cieszyn Shales, bounding these deluvia from the east (Fig. 8). The palaeosoil horizon, marked as PH2, developed in the upper part of unit g, was dated at 31 200 ± 100 years BP in the Laboratory of the Institute of Physics, Silesian Technical University (Gd-10391). This horizon originated in warm climatic conditions, as shown by the largest content of tree pollen in the entire section (45%). Deposits of unit h (thickness 2.6 m), of grain-size similar to that of deposits of unit g (bearing, however, a larger sand content and showing the presence of sandstone grains), and occurring in a similar geological setting, represent the middle solifluctional deposits (s3). As for unit d and e, unit j (1.5 m thick), due to its grain size parameters (Table 1), and heavy mineral content (Table 3), may be considered to represent the upper loess-like deposit (ls3). The low values of the loess indices (Table 1) and the heavy minerals composition similar to the nearby weathered deposits (Table 3), determined in the lower and upper loess-like deposits in the H-1 section, may point to slopewash processes during their accumulation.

Five lithological units (a–e) with a total thickness of 5.5 m (Fig. 9) were distinguished in the Sułkowice-1 (S-1) borehole section located in the central part of the Sułkowice Basin (Fig. 6). By analogy to the earlier described deposits from section H-1 and the geological and geomorphological setting of deposits in section S-1 (Fig. 10), it can be assumed that deposits of unit a represent weathered sediments (w), which are covered by loess-like deposits of units b–e, which explains the presence of small quantities of amphiboles (Table 3) in the weathered sediments derived from the loess-like deposits occurring above. The thick (5.3 m) unit of loess-like deposits is separated by a palaeosoil horizon, PH3, observed in the topmost part of unit c.

Silty clays below the palaeosoil horizon correspond to the middle loess-like deposits (ls2); lower values of skewness, curtosis and the loess index, as well as a slightly poorer sorting of depos-

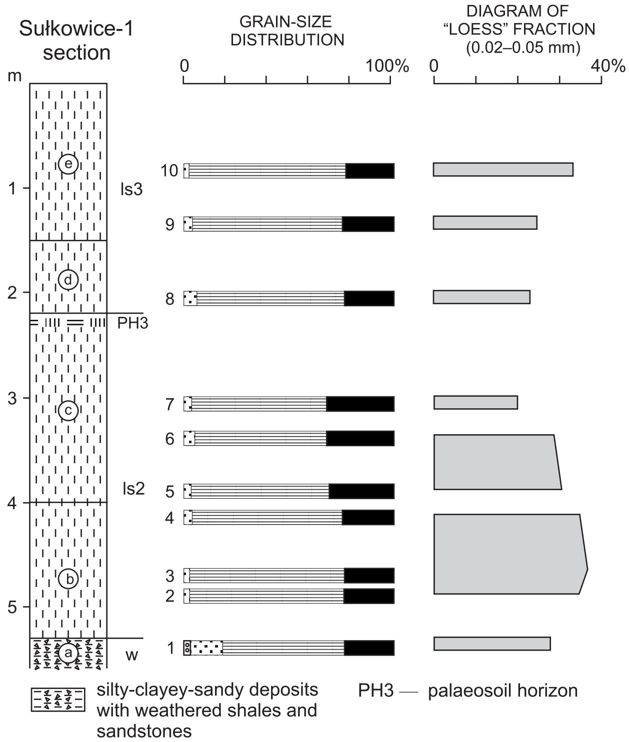


Fig. 9. Sułkowice-1 section

Other explanations as on Figure 7

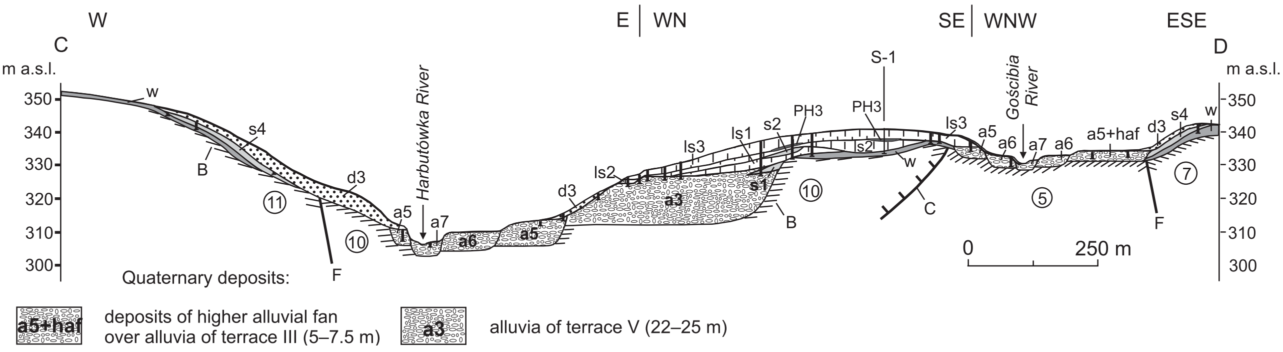


Fig. 10. Geological cross-section C–D through the middle part of the Sułkowice Basin

S-1 — Sułkowice-1 borehole; PH3 — palaeosoil horizon; other explanations as on Figure 8

its from unit c (Table 1) may suggest accumulation in more humid conditions or minor activity of slopewash processes. Clays occurring above the palaeosoil horizon (units d–e) represent the upper loess-like deposits (ls3). The large content of iron carbonates and a small amount of amphiboles (Table 3) shows that intense chemical weathering of these deposits has taken place.

Four lithological units (a–d) were distinguished (Fig. 11) in the Sułkowice-2 (S-2) section (total thickness *ca*. 3.5 m) in the northwestern part of the Sułkowice Basin (Fig. 6). The weathered shales and marls of the Istebna Beds (unit a) are covered by weathered deposits (w) of these rocks (unit b) and lower (s2) or middle (s3) solifluctional deposits (unit c). The solifluctional deposits include large grains of poorly weathered sandstones (sample 4 on Fig. 11). The youngest silty clays (unit d), with a higher content of the "loess" fraction (Fig. 11), the highest

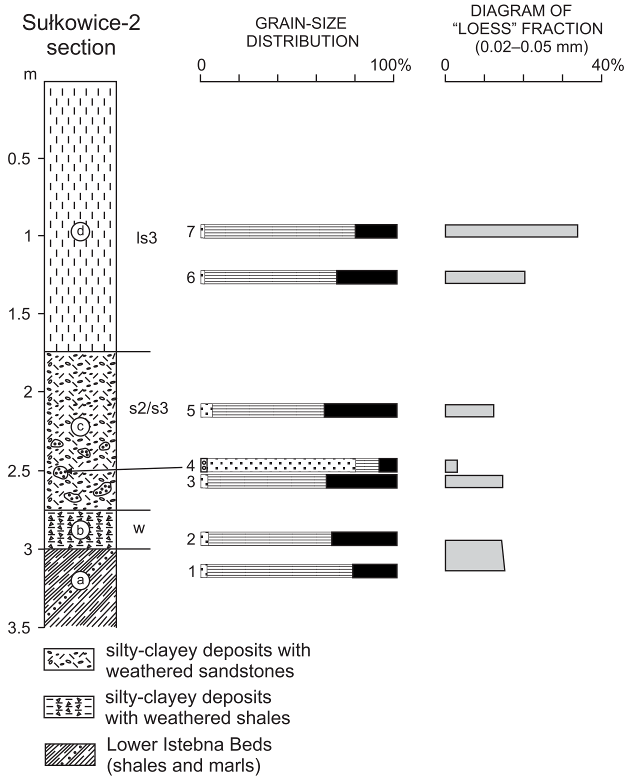


Fig. 11. Sułkowice-2 section

Other explanations as on Figure 7

loess indices (Table 1) and the presence of amphiboles (Table 3), correspond to the upper loess-like deposits (ls3).

Grain-size parameters and loess indicators of the Quaternary deposits from other borehole sections (Table 2) in the Sułkowice Basin are comparable to those of the sections discussed above (Table 1).

SELECTED BOREHOLE SECTION FROM THE LANCKORONA HILLS

Six lithological unit (a–f), up to 11 m in thickness (Fig. 12), were distinguished in the Jastrzębia-1 (J-1) borehole section, located in the lower part of the Jastrzębski Potok valley (Fig. 6). Their age and correlation with deposits studied in the Sułkowice Basin were determined by analyses (Tables 1 and 3) and position on the geological cross-section. The grain-size, low heavy mineral content (Table 3), and geomorphic setting (Fig. 13) indicate that the oldest deposits in section J-1 (unit a) are weathered sediments (w) of the variegated shales and marls (showing, therefore, the high $CaCO_3$ content), occurring in the basement. The poorly preserved palaeosoil horizon in the topmost part of these weathered deposits (at 8.5–8.7 m) is most probably the oldest organic horizon encountered in the study area and marked as PH1. The overlying silty-clayey clays (unit b) probably correspond to the lower solifluctional deposits (s2) from the Sułkowice Basin. Movement on slopes is indicated by the presence of a small content of amphiboles in these sediments, not observed in the older weathered deposits (Table 3), and probably resulting from solifluction of the loess-like deposits. All younger silty clays (unit c–f) in the discussed section (containing amphiboles — Table 3 and showing high loess indices — Table 1) are loess-like deposits separated by a palaeosoil horizon, as in section S-1. The palaeosoil was dated at 20 760 ± 300 years BP and it is marked as PH3. Clays from unit c (below PH3) are correlated with the middle loess-like deposits (ls2), whereas clays of units d–f (above PH3) — with the upper loess-like deposits (ls3). The upper loess-like deposits are subdivided into two parts (units d, f) by a layer of deluvial sediments (unit e), originated due to washing out of the loess material (as is indicated by the higher content of the clayey and sandy fraction, the smaller content of the "loess" fraction and the considerably lower loess index — Table 1). In the upper loess-like deposits, $CaCO_3$ occurs only in the lower part (4–4.5%). Decalcification reached down to 3 m, to the present ground water level, as in section H-1. In the other sections (J-2 and J-3) of this region, in the

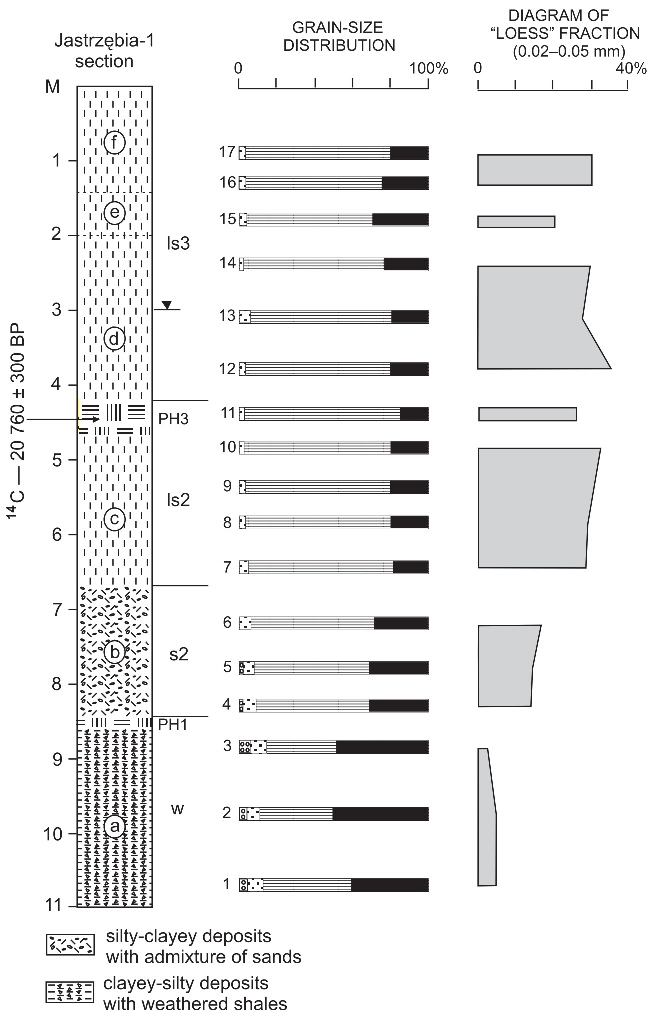


Fig. 12. Jastrzębia-1 section

PH1, PH3 — palaeosoil horizons; other explanations as on Figure 7

upper loess-like deposits amphiboles have also been found (Table 3). The youngest loess-like deposits have a wide extent in the Jastrzębski Potok valley (Fig. 13).

Besides these Quaternary deposits, other slope sediments were observed in the sections analysed. Their geological setting and extent are shown on geological cross-sections (Figs. 8, 10 and 13).

The oldest solifluctional deposits (s1) occur on alluvia of the Harbutówka terrace V (in some cases they interfinger with alluvia) and are covered by the lower loess-like deposits (Fig. 10). The upper solifluctional deposits (s4) commonly occur on the surface in the Sułkowice Basin (Figs. 8 and 10) and in the Lanckorona and Izdebnik Hills (Fig. 13). The upper deluvial deposits (d3), formed mainly due to the slopewashing of material from the loess-like covers (with a large silt content — up to 75%, and a considerable content of the "loess" fraction — 20–27%), have a wide distribution throughout most of the study area (Figs. 8, 10 and 13).

SELECTED BOREHOLE SECTIONS AND EXPOSURES IN THE GŁOGOCZÓW DEPRESSION

The origin and succession of Quaternary deposits in the Głogoczów Depression and Raba River valley were determined on the basis of grain-size and mineralogical analyses (Table 4) carried out for two boreholes, Polanka-1 (P-1, Fig. 14a) and Polanka-2 (P-2, Fig. 14b), the exposure in the "Polanka" brickyard (P-3, Fig. 14c), and analysis of geological cross-sections (Fig. 15). Correlation with deposits in the Sułkowice Basin and Lanckorona Hills is based on dating of the palaeosoil horizons (Fig. 14a), and a comparison of geological cross-sections. The following units were distinguished in the sections studied: weathered deposits — w (P-1, P-2), middle loess-like deposits — ls2 (P-2, P-3), middle deluvial deposits — d2 (P-1, P-2), middle solifluctional deposits — s3 (P-1), and upper loess-like deposits — ls3 (all sections). The middle

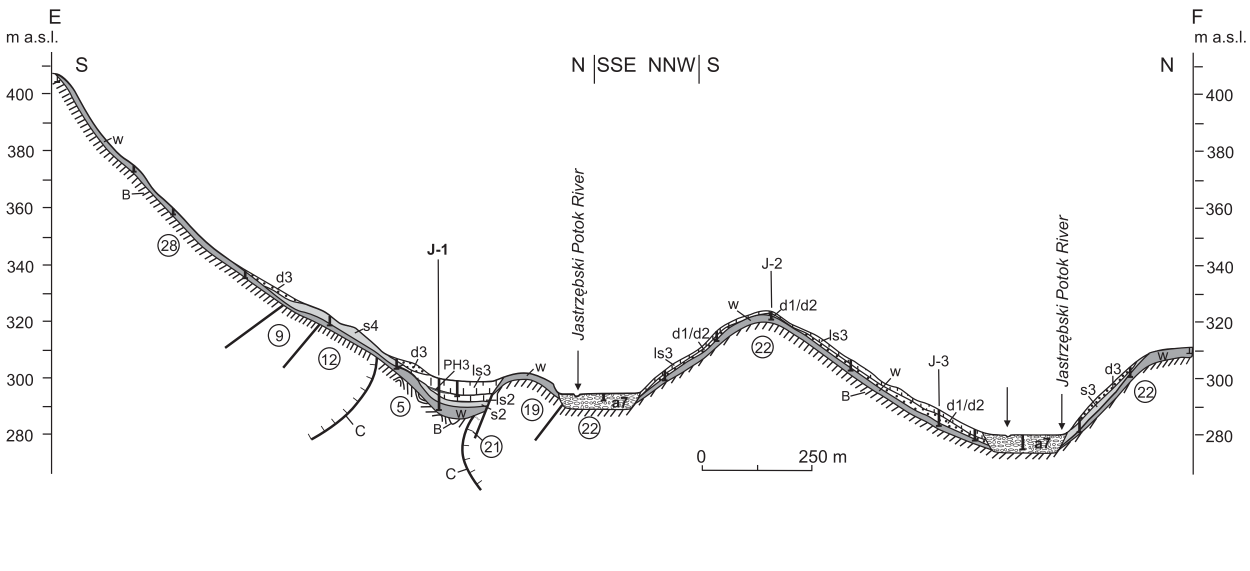
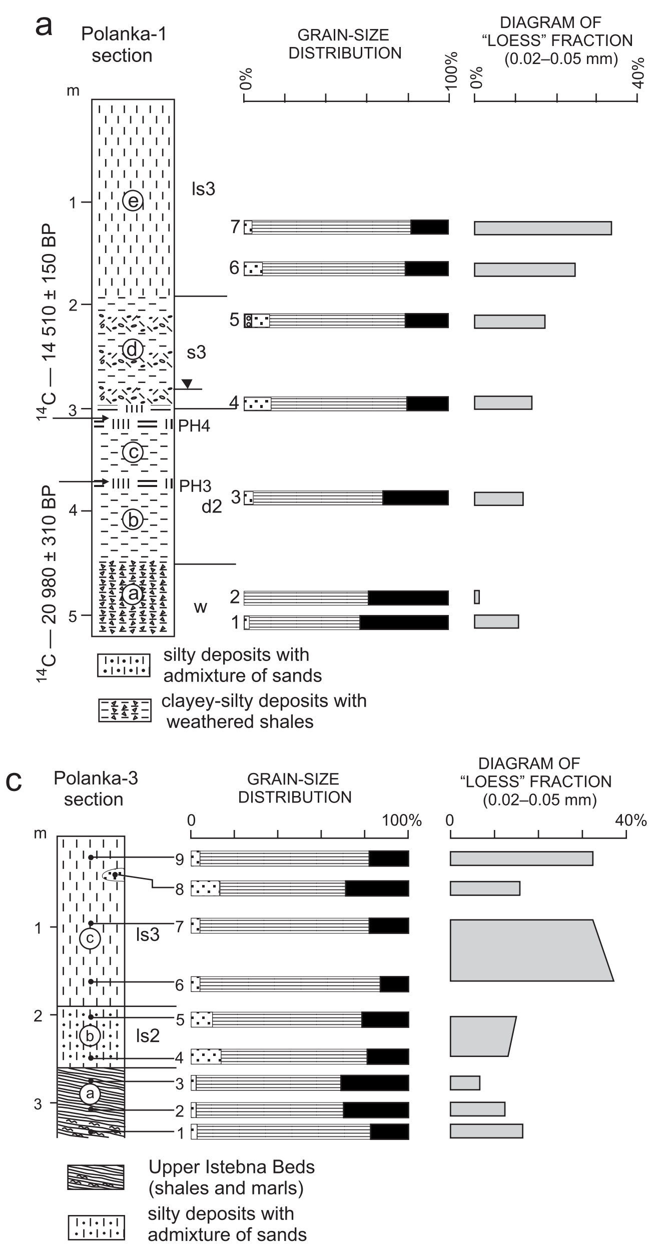


Fig. 13. Geological cross-section E–F through the Lanckorona Hills and Izdebnik Hills

J-1 — Jastrzębia-1 borehole, J-2 — Jastrzębia-2 borehole, J-3 — Jastrzębia-3 borehole; d1/d2 — lower deluvial deposits/middle deluvial deposits; other explanations as on Figures 8 and 10



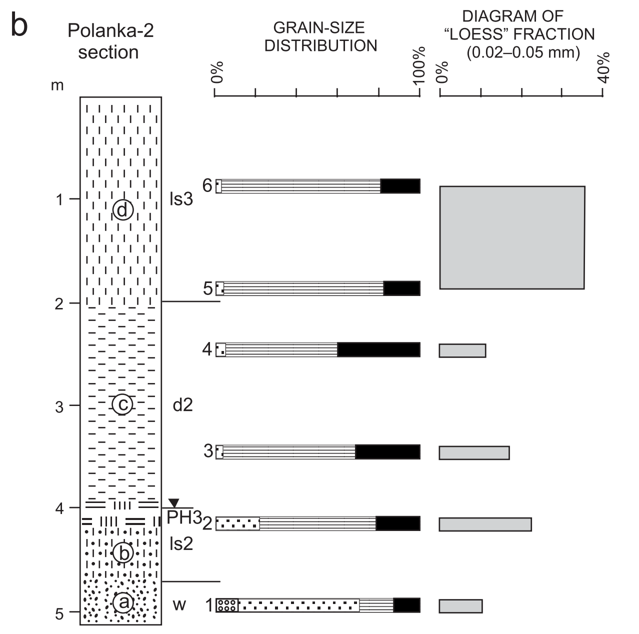


Fig. 14. a — Polanka-1 section; b — Polanka-2 section; c — Polanka-3 section

PH3, PH4 — palaeosoil horizons; d2 — middle deluvial deposits; other explanations as on Figure 7

loess-like deposits (ls2) are poorly preserved in the entire Głogoczów Depression and typically do not exceed 2 m (Fig. 15). These deposits were accumulated most probably due to minor washout processes, as is indicated by the local co-occurrence with lower deluvial deposits (Fig. 15 — cross-section G–H), a higher content of the sandy fraction, and the smaller content of the loess fraction (Figs. 14b and c). The middle deluvial deposits (d2), not observed within the Sułkowice Basin, occur commonly in this area and reach a thickness up to 2 m (Fig. 14a, b). The presence of amphiboles (Table 4) and calcium carbonate (up to 18.5%) in these deluvia links their origin with washout from the earlier accumulated middle loess-like deposits. Two palaeosoil horizons were determined within these deposits in the Polanka-1 section (Fig. 14a): the lower palaeosoil was dated at 20 980 ± 310 years BP (Lod-842) and, as it corresponds to the palaeosoils from sections J-1 and S-1, it is marked as PH3; whereas the upper palaeosoil (from a depth of 3.0–3.2 m), dated at 14 510 ± 150 years BP (Lod-838), is marked as PH4. The largest lateral distribution is observed for the upper loess-like deposits (ls3) covering the older deposits throughout the Głogoczów Depression (Fig. 15). Their characteristic features include a low $CaCO_3$ content (< 0.01%) and the presence of amphiboles, staurolite, disthene and andalusite in the heavy mineral composition (Table 4). In the Polanka-3 section, lenses of clayey material (Fig. 14c, sample 8) occur within these deposits, indicating soliflunctional downslope displacement of the frozen material taking place during the initial phase of loess accumulation. The thickness of the upper loess-like deposits varies from 2 to 4 m in the southern part of the Głogoczów Depression (Fig. 15) to 8 m in its northern part (boreholes in the "Polanka" brickyard).

"OSIECZANY" BRICKYARD SECTION (O-1)

Five units (Fig. 16) can be distinguished in the succession of Quaternary deposits (*ca*. 4 m thick) in the "Osieczany" brickyard situated in the lower part of the left Raba River valley slope (Fig. 6). The origin of these deposits was determined based on grain-size analysis (mineralogical determinations were not conducted) and comparison with the succession in the nearby "Myślenice" brickyard (Cegła and Starkel, 1967), which occurs in a very similar geomorphic setting (Fig. 17). Deposits of unit b are unquestionably weathered deposits (w) of the Upper Istebna Shales (unit a). Clayey clays of unit c, characterised by the highest clay fraction content in the entire succession, can be related to washout processes; thus they represent the middle deluvial deposits (d2) corresponding to series III of the "Myślenice" succession (*cf*. Cegła and Starkel, 1967). Clays of unit d have a higher

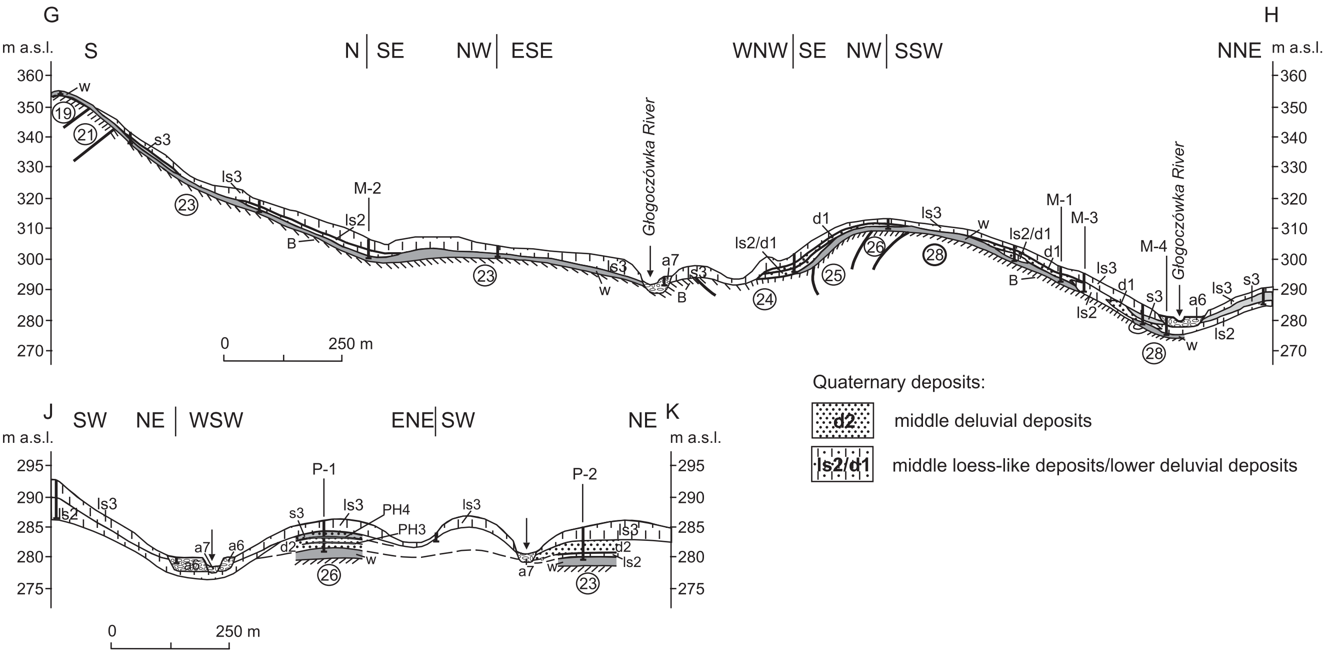


Fig. 15. Geological cross-sections G–H and J–K through the Głogoczów Depression

Boreholes: P-1 — Polanka-1, P-2 — Polanka-2, M-1 — Myślenice-1, M-2 — Myślenice-2, M-3 — Myślenice-3, M-4 — Myślenice-4; PH4 — palaeosoil horizon; other explanations as on Figures 8 and 10

content of the sandy fraction and their accumulation is linked with solifluction processes with minor participation of slopewash processes; therefore, they correspond to the middle solifluctional deposits (s3), occurring in the middle part of the "Myślenice" brickyard succession (series II — Cegła and Starkel, 1967). The youngest lithological unit e, comprising silty clays with a high content of the "loess" fraction, is of aeolian origin and corresponds to the upper loess-like deposits (ls3), and the youngest silty deposits in the "Myślenice" succession (series I — Cegła and Starkel, 1967). The higher content of the sandy fraction in these deposits indicates transport of coarser material or the participation of washout processes during the accumulation of the loess-like deposits.

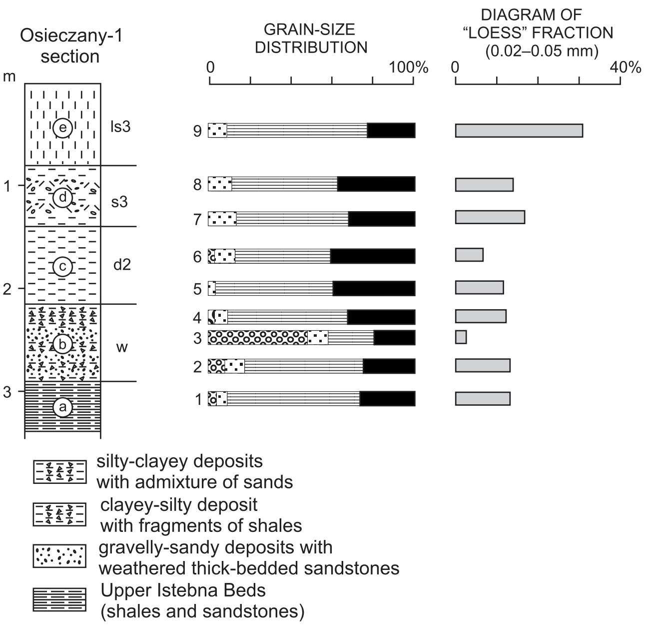


Fig. 16. Osieczany-1 section

Other explanations as on Figure 7

SUCCESSION OF FLUVIAL DEPOSITS IN THE RABA AND HARBUTÓWKA RIVER VALLEYS AND THEIR RELATION TO THE SLOPE AND LOESS-LIKE DEPOSIT

Alluvia of seven river terraces in the Raba and Harbutówka River valleys occur within the study area. The location and distribution of these deposits and their relation to the slope and loess-like deposits are shown on geological cross-sections through the Harbutówka (Figs. 8 and 10) and Raba River valleys (Fig. 17).

The oldest alluvia of terraces VII (a1) and VI (a2) are preserved only on the northern slope of the Raba River valley (northwards of Myślenice), on the watershed between the Skawina and Raba catchment areas (Fig. 17). The top surface of alluvia of terrace VII (most probably partly denuded) occurs at 64.5–68 m above the present Raba River channel; the rock-cut bench being situated at 58–60 m (Fig. 17). The top surface of the alluvia is occasionally covered by the upper loess-like deposits. Alluvia of terrace VI occur in form of an independent step situated below terrace VII. The height of the rock-cut bench of these alluvia is variable, 35–36 m and 39–41 m, being probably related to the variable resistance of the Istebna Beds. The upper surface of the alluvia occurs at 44–46 m and 46–51 m above the Raba River channel. The maximal thickness of alluvia of terrace VII is *ca.* 11 m, whereas that of alluvia of terrace VI is *ca.* 10 m. Alluvia of these terraces comprise mainly well-rounded (*ca.* 80%) clasts of sandstones (*ca.* 90%), and conglomerates (*ca.* 10%), which occur in a sandy-silty material (sand fraction 40–50%, silt fraction *ca.* 30%). The clasts display the largest lithological variability. Clasts of Magura Sandstones (*ca.* 40%) and of sandstones and conglomerates of the Istebna Beds (*ca.* 25%) prevail. The con-

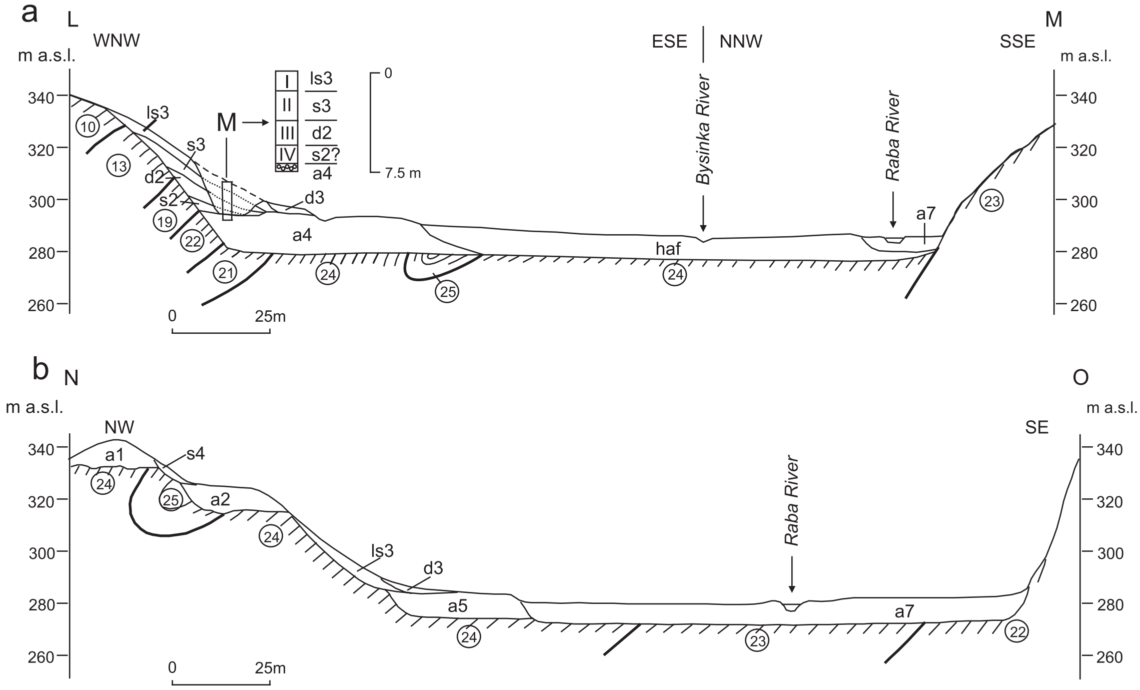


Fig. 17. Schematic geological cross-sections L–M and N–O through the Raba River valley

a1 — alluvia of the terrace VII (64.5–68 m), a2 — alluvia of the terrace VI (46– 51 mm), a4 — alluvia of the terrace IV (14–17 m); M — "Myślenice" brickyard section (according to Cegła and Starkel, 1967); haf — deposits of higher alluvial fans; d3 — upper deluvial deposits; other explanations as on Figure 8

tent of clasts of other origin (from the Godula, Grodno, Ciężkowice and Krosno Beds) is insignificant. Alluvia of the two highest terraces do not contain boulders of glacial or fluvioglacial origin; only local Carpathian material is present.

Alluvia of the five remaining river terraces also occur in the Harbutówka River valley. Alluvia of terrace V (Fig. 10 — a3) in the Harbutówka River valley are covered by loess-like deposits (ls1, ls2, ls3), as well as the oldest solifluctional deposits (s1), up to 8 m thick. The upper surface of these alluvia occurs at 19.5–25.0 m above the river channel. The rock-cut bench of this terrace is probably located 10–11 m above the present channel. These alluvia comprise clasts of the Magura and Ciężkowice Sandstones, rarely of the Krosno Sandstones, characterised by a different degree of roundness (large content of angular clasts). The clasts occur in a sandy or sandy-clayey mass. In the Bysinka River valley, *ca*. 10 m thick alluvia occur in the form of a large alluvial fan.

The top surface of alluvia of terrace IV (a4) lies at 6.5 m (in the Harbutówka River valley) to 14–17 m (in the Raba River valley — Fig. 17), and the rock-cut bench is situated at 3–5 m below the present Raba River channel. The observed thickness of these alluvia is from 10 m (in the Harbutówka River valley) to 15 m (in the Raba River valley). Alluvia of this terrace are developed as clasts of sandstones (mainly from the Magura and Krosno Beds) lying within a sandy-gravel-clayey material. The alluvia are covered almost entirely by the upper loess-like deposits and by soliflunctional and deluvial deposits (up to 4 m thick in the Harbutówka River valley), as in the "Myślenice" brickyard section (Fig. 17).

Alluvia of terrace III (a5) have a wide distribution in the Raba, Harbutówka, Gościbia and Bysinka River valleys (Figs. 8, 10 and 17). In the Gościbia River valley, they are developed as a 7 m thick gravel bed, divided by *ca*. 1 m clayey silts (silt fraction 45—50%, clay fraction 25–30%, sand fraction *ca*. 20%) into two parts. The top part of these alluvia occurs at 4–9 m above the river channel. Alluvia of terrace III in the Harbutówka River valley are, in some cases, covered by upper solifluctional (s4 — Fig. 8) and deluvial deposits (d3 — Figs. 8 and 10), and in other cases also by alluvia of higher alluvial fans (haf). In the Gościbia River valley, these alluvia are covered by the upper loess-like deposits (ls3), up to 2.5 m thick (on the western bank), and also (on the eastern bank) by deposits of the higher alluvial fan (haf — Fig. 10). The lithological variability of the boulders reflects the geological setting of the catchment areas. In alluvia of the Harbutówka River, clasts of the Magura Sandstones in a sandy-gravel material prevail between Harbutowice and Sułkowice, whereas clasts of the Magura and Istebna Sandstones in a gravel-clayey material prevail northwards of Sułkowice. In turn, the Gościbia River valley, almost entirely eroded into the Magura Beds, is characterised by the prevalence of clasts of the Magura Sandstones (60–80%) over clasts of the Ciężkowice (7–13%) and Godula (2–9%) Sandstones. In alluvia of the Bysinka River valley, clasts of the Godula sandstones (*ca*. 70%) prevail over clasts of the Lgota (*ca*. 25%) and hornstones (*ca*. 5%).

Alluvia of terraces II (a6) and I (a7) occur in the Raba, Harbutówka and Gościbia River valleys (Figs. 8, 10 and 17), and also in valleys of smaller streams. The top surface of terrace II lies at 1.5–6.5 m above the river channel, and that of terrace I is 0.5–3.5 m above the river channel. Alluvia of terrace II are occasionally covered by the upper deluvial deposits (d3), up to 1.5 m thick, and alluvia of lower alluvial fans. Alluvia of terrace I occur in the valleys of all larger rivers in the study area. In the Raba River valley they are inserted within the truncated, older alluvia of terrace III or of the higher alluvial fan (Fig. 17). The thickness of alluvia of terrace II reaches from 1–3 m (in the Gościbia River valley) to 5–6.5 m (in the Raba River valley). The thickness of alluvia of terrace I varies from 1–6 m (in the Harbutówka and Gościbia River valleys) to 4–8 m (in the Raba River valley). In the Raba, Harbutówka, Gościbia, Bysinka and Jasienica River valleys (generally eroded in sandstones and shales), the alluvia of the two largest terraces are developed mainly as gravels of resistant sandstones (of the Magura, Godula and Lgota Beds). In turn, in the Piezgówka, Głogoczówka River and Jastrzębski Potok valleys (eroded in the Istebna Beds, generally composed of moderately resistant sandstones and conglomerates), the alluvia comprise sands and gravels, interbedded with alluvial clays, where the content of gravels is insignificant. The heavy mineral composition of the youngest alluvia in the Głogoczów Depression includes amphiboles, staurolite, as well as disthene and andalusite (minerals characteristic of loess-like deposits — Table 4, M-4 section), the presence of which points to washout of younger loess-like covers (Grzybowski, 2001).

LITHOSTRATIGRAPHY OF QUATERNARY DEPOSITS

The lithostratigraphy of the Quaternary deposits was worked out by comparison of laboratory and palynological analyses, as well as by datings deposits from the H-1, J-1 and P-1 sections, and the results of investigations carried out by other authors in the Carpathian Foothills, Outer Carpathians, Małopolska and Lublin uplands. The stratigraphic position of the recognised alluvial horizons was based on the height of the rock-cut benchs, position of the accumulation surfaces for particular terraces, the cover of alluvia by younger slope and loess-like deposits, as well as the correlation and comparison to terraces of known age, occurring in other valleys in the Beskidy Mts.

SOUTH POLISH (ELSTERIAN) GLACIATIONS

The oldest Quaternary deposits in the study area are preserved in the Raba River valley and are linked with the fluvial accumulation of terraces VII (a1) and VI (a2). The location of the top and bottom of these deposits as well as their small thickness (1–9 m) are very similar to those of alluvia in the Dunajec River valley within the Rożnów Foothills, the accumulation of which is linked with the Nidanian and Sanian stages of the South Polish (Elsterian) Glaciations (Zuchiewicz, 1990, 1992). Authors of the Myślenice sheet of the *Detailed Geological Map of Poland* (Paul *et al*., 1996) also correlated the oldest alluvia in the Raba River valley with the South Polish Glaciations. Thus, alluvia of terrace VII probably accumulated in the Nidanian or Sanian 1 glaciations, whereas alluvia of terrace VI was deposited during in the Sanian 2 Glaciation.

MIDDLE POLISH (SAALIAN) GLACIATIONS

In the area studied, Quaternary deposits formed during the Middle Polish Glaciations (Saalian) occur in the Raba, Bysinka and Harbutówka River valleys and are linked with alluvia of terrace V (a3), which developed during the Wartanian Glaciation (Grabowski, 1996). Previous workers (Wójcik and Raczkowski, 1994; Paul *et al*., 1996) noted the presence of two terraces from the Middle Polish Glaciation in the Raba River valley. The first terrace was observed at 15–25 m and the second at 20–20 m; the lower horizon has been linked with the Wartanian Glaciation. The stratigraphic position of alluvia representing this terrace was based on the correlation and comparison with terraces of known age, occurring in the river valleys of Skawinka (15–25 m above the river channel; *cf.*Wójcik and Rączkowski, 1994), Soła (20–25 m above the river channel; Alexandrowicz, 1991), and Dunajec (15–25 m above the river channel; *cf.* Zuchiewicz, 1990, 1992, 1999).

In the Dunajec River valley (in its foothill stretches), the surfaces of terraces of the Middle Polish Glaciation are often covered by loesses, loess-like, solifluctional or deluvial deposits from the Vistulian Glaciation, as are the terraces in the Harbutówka River valley. The geological-geomorphic setting of the alluvia of terrace V in the Harbutówka River valley is similar to that of the alluvia from the Dunajec River valley (exposures in Glinki and Płusy), covered by thick silty-clayey and sandy covers (Butrym and Zuchiewicz, 1985). TL datings of these alluvial deposits indicated the Wartanian Glaciation, whereas the overlying deposits accumulated in the early glacial phase of the Vistulian Glaciation.

The origin of the oldest solifluctional deposits (s1) overlying alluvia of terrace V in the Harbutówka River valley may be linked with the younger part of the Wartanian Glaciation or the older part of the Vistulian Glaciation.

EEMIAN INTERGLACIAL

In the area studied, pollen analysis or dating did not document deposits from the Eemian Interglacial. It seems, however, that the origin of some weathered deposits (w), preserved in land depressions (H-1, S-1 and J-1 sections) and covered by younger Quaternary deposits, may be linked with this interglacial. These older weathered deposits generally developed due to chemical weathering, when favourable climatic conditions prevailed (Starkel, 1995).

VISTULIAN (WEICHSELIAN) GLACIATION

The lithostratigraphy of Quaternary deposits and a succession of selected geological processes from the youngest glaciation are presented on Figure 18.

EARLY STAGE OF THE VISTULIAN GLACIATION

The oldest deposits from the Vistulian Glaciation are represented by alluvia of terrace IV (a4) occurring in the Raba (11.0–14.5 m above the river channel) and Harbutówka River valleys (6.5–13.0 m above the river channel), being covered by slope and loess-like deposits. Based on correlation of these deposits with fluvial sediments of the other Carpathian river valleys — Skawinka and Raba (6–15 m; *cf.* Wójcik and Rączkowski, 1994), Soła (15–17 m; *cf.* Alexandrowicz, 1991), and Skawa (Koperowa and Środoń, 1965; Bińka and Grzybowski, 2002 — Świnna Poręba section), it can be in-

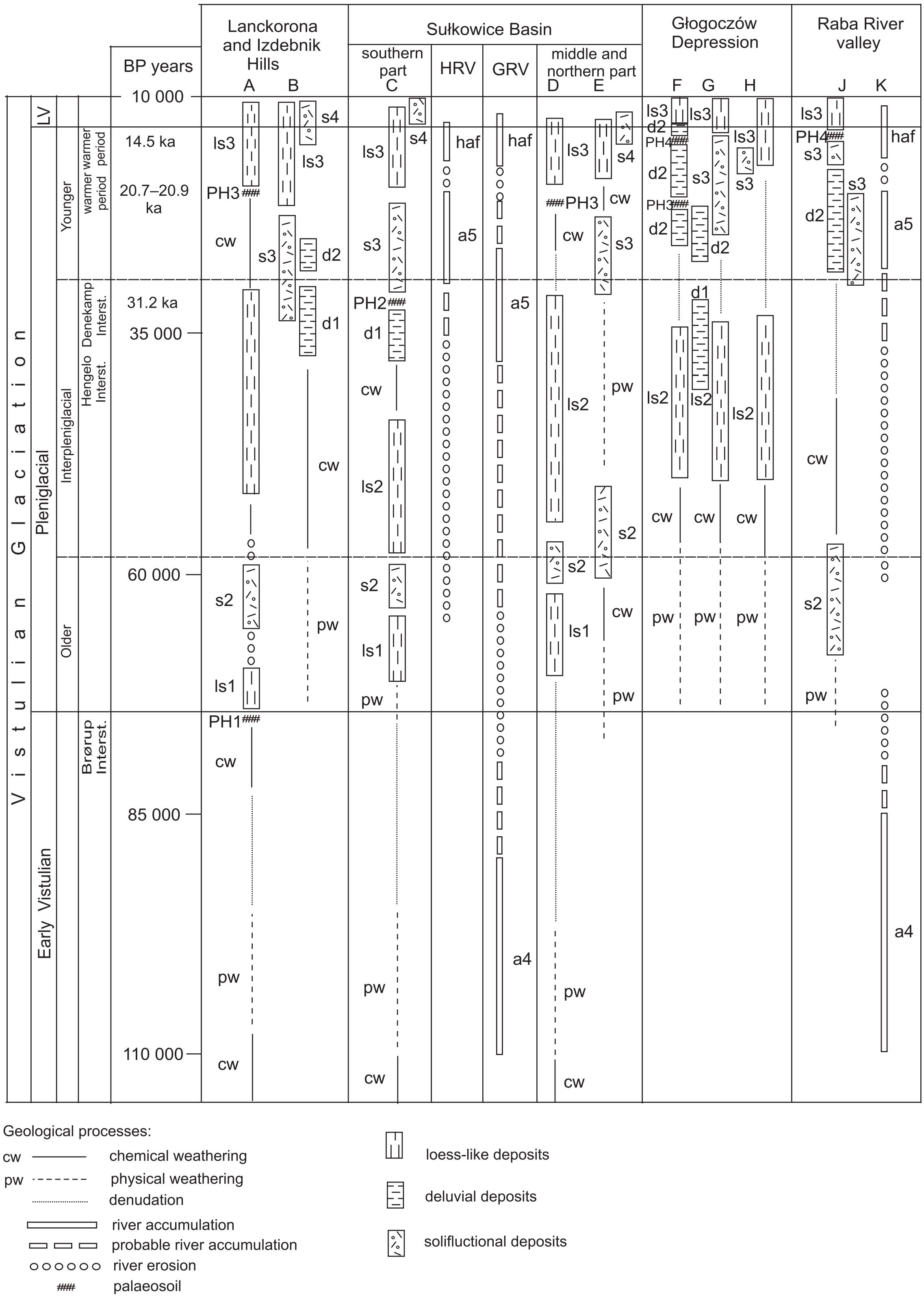


Fig. 18. Scheme of stratigraphy of the Quaternary deposits and some geological processes during the Vistulian Glaciation in regions investigated in the study area

Stratigraphy of Quaternary deposits is based on following sections and cross-sections: A — J-1 section, B — cross-section E–F, C — H-1 section and cross-section A–B, D — S-1 section and cross-section C–D, E — S-2 section, F — P-1 and P-2 sections and cross-section J–K, G — cross-section G–H, H — P-3 section, J — O-1 and M-1 sections, K — cross-sections L–M and N–O; PH1–PH4 — palaeosoil horizons; LV — Late Vistulian, HRV — Harbutówka River valley, GRV — Gościbia River valley; other symbols as on Figures 7 and 14a, b ferred that alluvia of terrace IV originated in the early stage of the Vistulian Glaciation. It cannot, however, be excluded that the fragmentarily preserved alluvial horizon IV was accumulated later and is contemporary with alluvia of terrace III.

The formation of a palaeosoil horizon (PH1) in section J-1 (at 8.5–8.7 m) may be linked with one of the first interstadial warmings in the Vistulian Glaciation (possibly the Brørup Interstadial).

OLDER PLENIGLACIAL, INTERPLENIGLACIAL, YOUNGER PLENIGLACIAL AND LATE GLACIAL

The formation of majority of the weathered deposits (w) is linked herein with the Pleniglacial, particularly with the Interpleniglacial warming, when chemical weathering was more intense than during the other parts of the Vistulian Glaciation (Starkel, 1995). In cases when these deposits were not covered by other deposits they underwent transformation in the late stage of the Vistulian Glaciation and the Holocene.

Lithostratigraphy of slope deposits of Quaternary age encompassing the younger part of the Vistulian Glaciation was best documented in the H-1, J-1 and P-1 sections, mainly based on ^{14}C datings of the palaeosoil horizons. The palaeosoil in the Harbutowice-1 section (PH2) was dated at 31 200 ± 1000 years BP; this date along with pollen data allows relation of this soil to the Denekamp Interstadial. Dates obtained from the palaeosoil (PH3) in the Jastrzębia-1 (20 760 ± 300 years BP) and Polanka-1 (20 980 ± 310 years BP) sections point to the middle part of the Younger Pleniglacial. The date from the youngest palaeosoil horizon (PH4) in the Polanka-1 section (14 510 ± 150 years BP) indicates its formation in the terminal part of the Younger Pleniglacial.

Based on dates and on geological-geomorphologic setting, the lower loess-like deposits (ls1), observed much below (9 m) the palaeosoil horizon (PH2) in the Harbutowice-1 section, accumulated in the Older Pleniglacial (Fig. 18); thus, they represent the lower younger loess.

The formation of the lower solifluctional deposits (s2) covering the oldest loess-like deposits in the H-1 section can be linked with the Older Pleniglacial (Fig. 18). Solifluctional deposits of series IV (overlying on alluvia of terrace IV from the early stage of the Vistulian Glaciation) and occurring in the "Myślenice" brickyard section were considered by Cegła and Starkel (1967) to represent the Older Pleniglacial.

The occurrence of the middle loess-like deposits (ls2) *ca.* 3.5 m below the palaeosoil horizon (PH2) from the Denekamp Interstadial in the H-1 section, allows their accumulation to be linked with the older part of the Vistulian Interpleniglacial (Fig. 18); therefore these deposits (5 m thick) can be correlated with the middle younger loess (Alexandrowicz *et al*., 1991; Łanczont, 1995). The decalcification of the upper part of these loess-like deposits indicates the presence of warmer climatic conditions, which may be linked with a warming during the Hengelo or Denekamp interstadials. It cannot be, however, excluded that the decalcification took place later. In the Głogoczów Depression, the formation of the discussed loess-like deposits was disrupted by intense denudation during the terminal part of the Interpleniglacial (Fig. 18), as is indicated by their occurrence directly upon flysch rocks in exposure P-3. The accumulation of the middle loess-like deposits preserved in the S-1, J-1 and P-1 sections lasted longer (probably to the end of the Interpleniglacial) than in section H-1 (where it was disrupted by slopewash processes) and terminated with the development of a palaeosoil horizon (PH3 — 20 760 ± 300 years BP and 20 980 ± 310 years BP) in the middle part of the Younger Pleniglacial (Fig. 18).

The palaeosoil (PH2) from the Denekamp Interstadial developed on top of the lower deluvial deposits (d1) in the H-1 section indicates that the discussed deluvia originated in the younger part of the Interpleniglacial (Fig. 18). In the Głogoczów Depression, their accumulation took place simultaneously with the accumulation of the middle loess-like deposits. Due to intense denudation at the Interpleniglacial/Younger Pleniglacial boundary, most of these deluvia as well as older deposits (particularly the middle loess-like deposits) were removed.

The accumulation of the middle deluvial deposits (d2), observed in the Głogoczów Depression and on the Raba River valley slopes, took place in the Younger Pleniglacial (Fig. 18), as is supported (section P-1) by the presence of two palaeosoil horizons: PH3 (20 980 ± 310 years BP) and PH4 (14 510 ± 150 years BP) within them.

The middle solifluctional deposits (s3), best preserved in the H-1 section above the palaeosoil horizon (PH2 — 31 200 ± 1000 years BP), developed in the older part of the Younger Pleniglacial in periods of more intense supply of the weathered material into river valleys (Starkel, 1995). Similar deposits observed directly on palaeosoil PH4 (14 510 ± 150 years BP) in the P-1 section accumulated in the terminal part of the Younger Pleniglacial (Fig. 18). Deluvial and solifluctional accumulation in the Younger Pleniglacial is also supported by the presence of slope deposits in the "Myślenice" brickyard section (series III and II *cf*. Cegła and Starkel, 1967). The organic horizon bearing fossil shells occurring within series II may correspond to palaeosoil PH4 in the Polanka-1 section.

Alluvia of terrace III (a5) occurring in the valley bottoms of the Raba, Bysinka, Harbutówka, Gościbia, and Jasienica rivers also developed during the younger part of the Vistulian Glaciation (Fig. 18). The glacial age of these alluvia is supported by the presence of the upper solifluctional deposits (s4) on their top, as well as upper loess-like deposits (ls3) which are up to 2.5 m thick. Recent investigations carried out in other Carpathian river valleys (Soła, Skawa, Dunajec, Wisłoka, Raba) pointed out that alluvia occurring at 6–10 m, in some cases covered by the upper younger loesses and deluvial-solifluctional deposits (that is, in a similar setting to alluvia of terrace III), developed during the Younger Pleniglacial or the Late Glacial (Zuchiewicz, 1990, 1992; Alexandrowicz, 1991; Paul *et al.*, 1996). This interval is the time of the most intense cooling caused by the maximal extent of the ice sheet of the last glaciation (Klimaszewski, 1967; Starkel, 1968, 1969).

The accumulation of alluvia of higher alluvial fans (haf), occurring in the Harbutówka (under upper solifluctional and loess-like deposits) and Raba River valleys was linked with the Younger Pleniglacial and the Late Glacial (Starkel, 1972).

The upper loess-like deposits (ls3) showing the widest lateral extent in the study area accumulated in the Younger Pleniglacial (in the J-1 section these deposits occur directly on palaeosoil PH3 — 20 760 ± 300 years BP) and the Late Glacial (in the P-1 section the discussed deposits occur above palaeosoil PH4 — 14 510 ± 150 years BP); thus, they represent the upper younger loess. The upper loess-like deposits correspond to the youngest silty deposits (series I) in the "Myślenice" brickyard succession, which accumulated in the Late Glacial (Cegła and Starkel, 1967). The occurrence of these deposits above palaeosoil PH4 in section P-1 (14 510 ± 150 years BP) indicates intense loess accumulation (up to 8 m thick) in the Late Glacial, as in the loess section from Zwierzyniec (14 200 ± 200 years BP — Konecka-Betley and Madeyska, 1985), in the vicinity of Cracow (14 800 ± 300 years BP, Rutkowski, 1993), and Roztoka in the Rożnów Foothills (Butrym and Zuchiewicz, 1991). TL and ^{14}C dates obtained from the loess section in the Vistula River valley in the vicinity of Kraków point to intense aeolian accumulation of the youngest loesses between 24–15 ka (Rutkowski, 1993).

Intense solifluctional processes took place in the terminal part of the Younger Pleniglacial, which resulted in the accumulation of upper solifluctional deposits (s4). The observed solifluctional structures in the upper loess-like deposits (section P-3) confirm that the accumulation of the youngest slope (s4) and loess-like deposits (ls3) took place simultaneously (Fig. 18).

HOLOCENE

Alluvia of terrace II (a6) developed most probably in the Holocene, as indicated by hypsometric comparison with terraces considered as Holocene in age, occurring at a similar level in the other Carpathian river valleys (Skawa — Książkiewicz, 1974*a*, *b*; Dunajec — Zuchiewicz, 1990; Soła — Alexandrowicz, 1991; Raba — Wójcik and Rączkowski, 1994). However, investigations carried out in the Skawa River valley (Bober *et al*., 1980; Grzybowski and Bińka, 1994) indicate that the accumulation of these alluvia could already have begun by the end of the Younger Pleniglacial.

In some cases, the upper deluvial deposits (d3) occur upon surfaces of alluvia of terraces II and III. The accumulation of these youngest slope deposits was most intense at the beginning of the Holocene (before the advance of vegetation on the Carpathian slopes), as well as during slope deforestation phases; i.e., in the Sub-Atlantic phase (Starkel, 1960, 1995).

Accumulation of alluvia of terrace I (a7), occurring at 0.5–5.5 m, took place in the Holocene, as in many other river valleys.

The alluvia of lower alluvial fans (ubiquitous in the Harbutówka, Gościbia and Piezgówka River valleys) represent the youngest Quaternary deposits in the study area, and their accumulation probably continues at present during high water stages in the streams.

PROBLEM OF THE MAXIMUM ICE SHEET EXTENT IN THE STUDY AREA

The Izdebnik Hills and Głogoczów Depression were areas where earlier investigators found the best preserved, although strongly weathered, glaciogenic deposits linked with the activity of the ice sheet during the South Polish (Elsterian) Glaciations (Klimaszewski, 1948; Książkiewicz, 1953; Dudziak, 1961, Paul *et al*., 1996).

Detailed investigations carried out in this study do not confirm the presence of typical glacial deposits or of individual erratic boulders in the area. As in Dudziak (1961), it is assumed that the individual erratic boulders found in the vicinity of Biertowice and Izdebnik are linked with fluvioglacial transport and not with ice sheet cover.

Relatively rare erratic boulders found by previous investigators in the vicinity of Wola Radziszowska (beyond the study area; *ca*. 1 km NW of Bugaj) indicate the close distance of the ice front in relation to the northern margins of the study area. It cannot be also excluded that the glaciogenic deposits occurring in the form of lobes (as in the vicinity of Głogoczów) in the northern part of the study area were denuded or eroded (strong denudation due to intense washout took place in the Younger Pleniglacial in the northern part of the Głogoczów Depression). This possibility is indicated indirectly by the moderately common occurrence of easily weatherable heavy minerals (amphiboles) within the deluvial and solifluctional deposits in the Głogoczów Depression and Izdebnik Hills (slope deposits in the Sułkowice Basin do not contain amphiboles). Most amphiboles were transported by winds, their origin by the denudation of *in situ* glacial deposits cannot, however, be excluded.

DISCUSSION AND CONCLUSIONS

The lithostratigraphy of Quaternary deposits worked out on the basis of the succession shown in cross-sections and in boreholes (H-1, S-1, J-1, P-1, P-2) and surface sections (S-2, P-3 and O-3) encompasses a large part of the Quaternary: from the Nidanian Glaciation to the Holocene.

Detailed lithostratigraphy based on ^{14}C dates of the observed palaeosoil horizons and pollen analysis of deposits of the H-1 section was applied to deposits of Vistulian age. Four palaeosoil horizons, corresponding to interstadial warmings (PH1 — probably of the Brørup Interstadial, and PH2 — 1 200 ± 1000 years BP — of the Denekamp Interstadial) and warmings during the Younger Pleniglacial (PH3 — 20 980 ± 310 years BP, 20 760 ± 300 years BP, and PH4 — 14 510 ± 150 years BP) can be distinguished. Loess-like deposits, accumulated during the Vistulian Glaciation, form three sets of different age: the lower (formed during the Older Pleniglacial), middle (formed in the Interpleniglacial and in the older part of the Younger Pleniglacial), and upper set (formed in the younger part of the Younger Pleniglacial and in the Late Glacial) which probably correspond to the lower, middle and upper younger loesses from other parts of Poland. Four horizons of solifluctional deposits have also been distinguished. The oldest is probably to be connected with the Wartanian Glaciation and the three younger horizons developed during the Vistulian Glaciation. The lower solifluctional horizon formed during the Older Pleniglacial and at the beginning of the Interpleniglacial, the middle one during the Younger Pleniglacial; and the upper one in the terminal part of the Younger Pleniglacial and in the Late Glacial. Three horizons of deluvial deposits (the lower from the younger part of the Interpleniglacial, the middle from the Younger Pleniglacial, and the upper from the Holocene) were also observed.

Fluvial deposits accumulated during several intervals, namely: in the Nidanian or Sanian 1 Glaciation (alluvia of terrace VII in the Raba valley — 64.5–68.0 m), Sanian 2 Glaciation (alluvia of terrace VI in the Raba valley — 44.0–51.0 m), Wartanian Glaciation (alluvia of terrace V in the Raba — 20.0–21.5 m, Harbutówka — 19.5–25.0 m and Bysinka River valleys — 20.0–23.0 m), early Vistulian Glaciation (alluvia of terrace IV in the Raba — 11.0–14.5 m and Harbutówka River valleys — 6.5–13.0 m), Pleniglacial (alluvia of terrace III — 4.5–9.0 m), Late Glacial (alluvia of higher alluvial fans), and Holocene (alluvia of terraces II — 1.5–6.5 m and I — 0.5–5.5 m and lower alluvial fans).

The presence of glacial deposits pointing to the direct cover of the study area by the ice sheet was not confirmed; thus, the problem of the maximuim range of the Scandinavian ice sheet remains open.

Radiometric dates indicate that a warming episode took place (marked by the formation of palaeosoil PH3 in sections S-1, J-1, P-1 and P-2) during the younger part of the Younger Pleniglacial (20.76 ka and 20.98 ka) in the entire area. This interval was also the time of maximum development of the Vistulian ice sheet during the Main Stadial in central and northern Poland. Therefore, it was a time of maximal cooling during the last glaciation. Thus, is it possible that climatic conditions favouring the formation of initial soils prevailed in some areas in the Carpathians or their foothills?

Based on the most recent concepts on the palaeogeography of the Carpathians and their foreland, the formation of palaeosoil horizons in southern Poland during the maximum extent of the youngest ice sheet seems plausible. The data obtained indicate that accumulation of organic deposits in the Carpathian Foothills in Poland during the Main Stadial was possible. In Podegrodzie on the Wisłoka River a layer of peaty silts was dated at 22.45 ka, and the presence of *ca*. 50% of tree pollen indicates that patches of steppe-forest and steppe-tundra communities were preserved (Mamakowa and Starkel, 1977). In the Wisłoka River valley near Brzeźnica organic intercalations occur in alluvial plain deposits dated at 21.3 ka (Mamakowa and Starkel, 1974). In Zalesie on the Przemyśl Foothills, shells of aqueous molluscas indicating a humid basement and a rich vegetation occur in the upper part of the upper younger loesses. Based on this, Łanczont (1995) deduced a warming dated at 25–21 ka. In the Konin–Maliniec section, a younger organic horizon containing tundra vegetation was formed at *ca*. 22 ka (Lindner, 1992) in the direct vicinity of the ice front.

The examples given show that the formation of initial soils in the southern part of the Wieliczka Foothills was probable even during the strongest cooling of the Vistulian.

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