

Preglacial to Holocene auriferous sediments from the East Sudetic Foreland: gold grades and exploration

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Auriferous sediments in the East Sudetic Foreland region include up to five gold-bearing horizons associated with preglacial and Quaternary fluvial sediments. The largest placer potential lies in the preglacial (Eopleistocene?) drainage system, primarily in palaeochannels of the Biała Głuchołaska River. The White Gravel series is the richest gold-bearing horizon. It contains between 0.37 g/m³ Au near the base and <0.10 g/m³ Au in its upper part. Maximum gold grade occurs in the first 1–2 m above the contact with the bedrock. Gold concentration in this area was controlled by the ability of streams to aggradation and the development of sedimentologic traps, where gold was accumulated during the preglacial valley erosion. Oblique orientation of the palaeo-Biała Głuchołaska valley and its tributaries to the regional ice-flow direction probably prevented the glaciers from eroding deeply into the palaeochannels. From the exploration prospective, study of palaeochannel systems in the vicinity of Otmuchów–Prudnik could identify other buried placer gold occurrences. Gold-bearing sediments, correlated stratigraphically with the Biała Głuchołaska palaeochannel White Gravels occur in several other areas, including the Nysa Kłodzka, Kwisa and Kaczawa valleys.

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INTRODUCTION

In the vicinity of Otmuchów–Prudnik (the East Sudetic Foreland) the preglacial and Quaternary fluvial sediments, overlying the Neogene sediments of the Poznań Formation, or Palaeozoic metamorphic rocks (Wierchowiec, 2002a, b), contain up to five gold-bearing horizons. The distribution of these horizons is highly discontinuous because of the Scandinavian glaciations (base-level changes), extensive post-glacial erosion and neotectonic movements (Wroński, 1975; Badura *et al.*, 1998; Badura and Przybylski, 1998; Przybylski, 1998).

The preglacial uneroded gold-bearing horizons are commonly buried by thick successions of Pleistocene and Holocene sediments (e.g. buried placer deposits in a glaciated part of northwestern British Columbia, the Klondike Plateau, the arctic shelf of Siberia or West Sudetic Foreland) (Wojciechowski, 1993, 1994; Patyk-Kara, 1999; Levson and Blyth, 2001; Duk-Rodkin *et al.*, 2001). Consequently, a detailed study of the local glacial history and geomorphology, as well as the geology of the gold-bearing horizons and their overburden, is required

to identify and evaluate potential buried gold placer deposits. Additionally, the combined analysis of gold grains morphology, chemistry and internal structures is needed to delineate the origin of the placers (Hérail *et al.*, 1990; Seeley and Senden, 1994; Eyles, 1995; Knight *et al.*, 1999; Lange and Ginoux, 1999; Wierchowiec, 2001).

This paper presents the results of an investigation of the placer gold occurrences in a glaciated part of the East Sudetic Foreland (Fig. 1). Auriferous deposits in that region are associated with so-called “preglacial” fluvial series (formed between the Pliocene and the Middle Pleistocene) and Holocene alluvial sediments.

The preglacial fluvial deposits in the Sudetic Foreland were formerly interpreted as one lithostratigraphic unit, known as the “White Gravels” (Zeuner, 1928; Behr and Mühlen, 1933; Wroński, 1975). From the beginning of 1970s, the definition of this series was supplemented by sandy sediments exposed near Gozdnicza and Ruzów, and called the Gozdnicza Formation (Dyjur, 1970, 1984) or the Ziębice Group (Czerwonka and Krzyszkowski, 2001). Because the details of further subdivision of Gozdnicza Formation are not clear, in this paper the au-

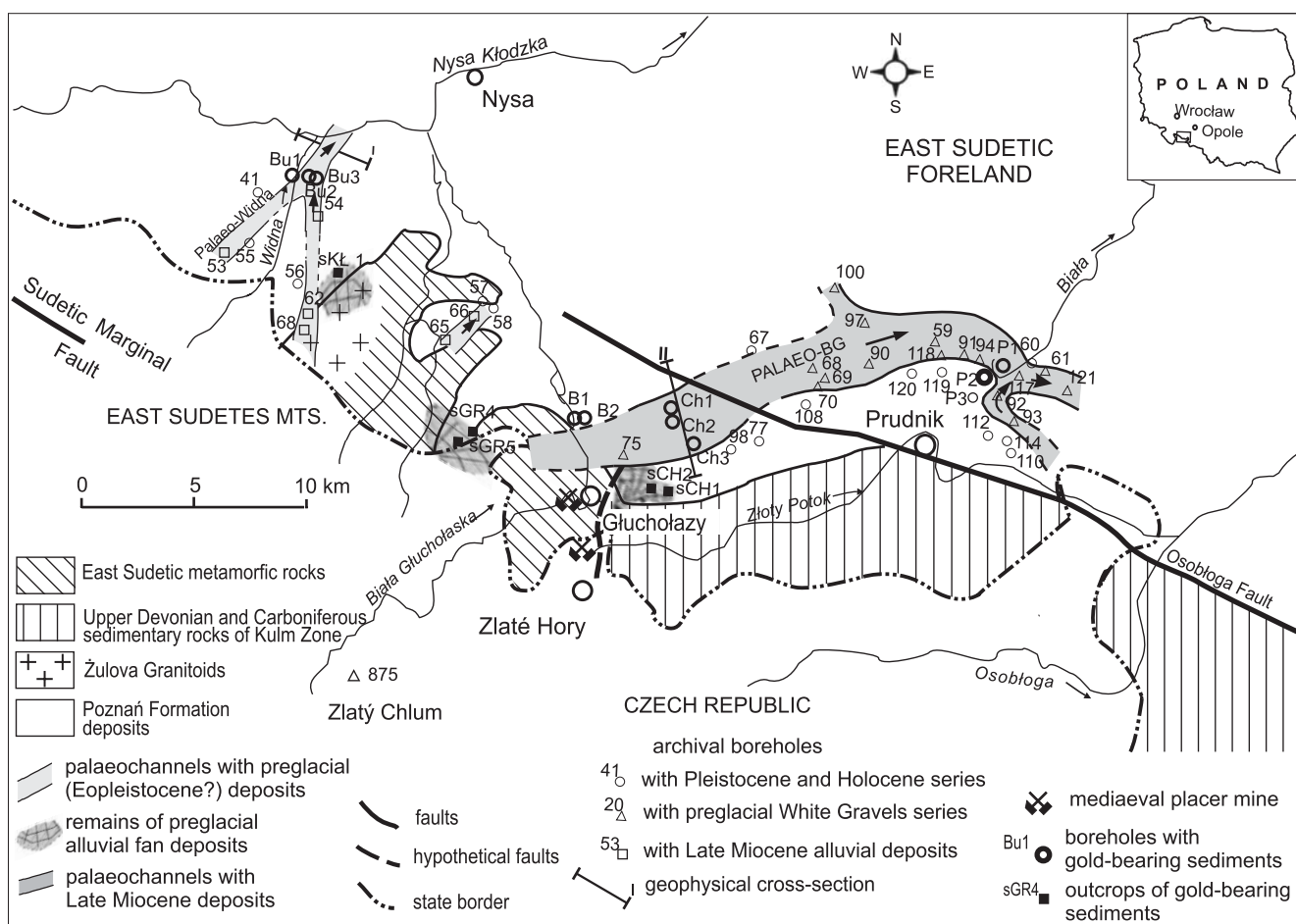


Fig. 1. Simplified geologic map of the East Sudetes and its foreland (without Quaternary cover), showing the location of sections studied in relation to the archival boreholes used for the reconstruction of palaeochannels with auriferous sediments (modified after Wierchowicz, 2002a; Godlewski and Wierchowicz, 2004); the approximate extent of palaeochannels with gold-bearing deposits and gold sampling sites for this study

thor usually uses the name “preglacial” for the all fluvial sediments post-dating the Poznań Formation and pre-dating the Elsterian Glacial sediments (*cf.* Badura and Przybylski, 1999, 2004). The occurrence, lithology and stratigraphic subdivision of preglacial deposits in the Sudetic Foreland has been discussed by Przybylski (1998), Przybylski *et al.* (1998), Badura and Przybylski (1999), Przybylski and Badura (2001).

Potentially gold-bearing, preglacial gravels and gravelly diamictons occur on plateaus and infill bottoms of palaeochannels (Dyjur *et al.*, 1978; Badura and Przybylski, 1994). Detailed palaeogeographic analysis has recently shown that some deeply-cut palaeochannels are filled by glacial material, including redeposited sediments of the Gozdnicza Formation (Badura and Przybylski, 2004).

The morphology, surface textures and chemical composition of gold particles support the view that the placer gold occurrences in the Otmuchów–Prudnik area are multicycled (recycled palaeoplacers) and multisourced (Wierchowicz, 2002a).

Results of this study can provide exploration guidelines for potential buried placer gold deposits in the other regions in the Sudetes Mts.

SAMPLING METHODS

10 and 90 litres samples (size depending on the nature of the sediments) were collected for heavy mineral analysis from five outcrops and 11 cored holes drilled during this project (Fig. 1). Each borehole was logged and sampled for gold grades.

After grain sorting on 2 mm sieve, each sample was panned to a “grey” concentrate level. Obtained heavy mineral concentrates were divided into ferromagnetic, paramagnetic and non-magnetic fractions using magnetic separation (Ventouse type) (Parfenoff *et al.*, 1970; Jęczmyk, 1974). Light part of non-magnetic fraction was removed by separation in bromoform. Gold grains were then separated from heavy mineral concentrates by hand-picking using a binocular microscope. Gold content was expressed by a number of grains in each sample and by weight, if gold concentration was above 0.10 g/m^3 . Heavy mineral identity and quantity was established in the representative fraction of 0.06–0.12 mm (Grodzicki, 1972; Godlewski and Wierchowicz, 2004) by using transmitted and reflected light microscope. Some minerals were evaluated as groups, denoted by the general name (amphibole,

pyroxene and garnet). The questionable minerals were identified by X-ray analysis and an EDS system attached to electron microscope.

In addition, each gold-bearing horizon was sampled for sediment grain-size analysis. Sand fraction was analysed by sieving. The particle size distributions of silt and clay fractions (<0.062 mm) were determined by the aerometric method. Particle size distribution curves of 16 representative samples were used to determine the mean diameter (Mz) and sorting. Statistical grain-size parameters were calculated according to the formulas of Folk and Ward (1957).

GOLD GRADES OF THE AURIFEROUS SEDIMENTS

The gold-bearing occurrences in the Otmuchów–Prudnik area are associated with preglacial piedmont fans, preglacial river systems and Late Quaternary alluvial sediments of the Biała Głuchołaska River and its tributaries, as well as of the Widna and Złoty Potok streams (Fig. 1).

The preglacial, gold-bearing palaeochannels are buried Pleistocene and Holocene sediments. The thickness of these deposits varies from 3.5 to 20 m but locally may reach up to 50 m (Przybylski and Badura, 2002). The overlying series was deposited by two glaciations and contains three till beds, diamictons, fluvial sands and gravels, and some fine-grained sediments (sandy silts, silts and clays). Description and interpretation of the main gold-bearing horizons is provided below.

PIEDMONT FANS GOLD-BEARING HORIZON

The lowermost, piedmont fans horizon overlies the Late Miocene sediments of the Poznań Formation, or Palaeozoic metamorphic rocks (Fig. 1). The palaeofans probably originate from the Neogene weathering cover of the Sudetes. Deposition of coarse-grained sediments resulted in development of piedmont alluvial fans along the northern margins of the East Sudetes (Wroński, 1975; Dyjor, 1975, 1984, 1987; Dyjor *et al.*, 1978; Badura and Przybylski, 2004).

The alluvial fan deposits were eroded and reworked during the preglacial time and Pleistocene. The total thickness of this series is not known, but limited borehole data suggest thickness varying between 2 and 20 metres (Sawicki, 1972). Distal parts of the palaeofans are not exposed because of intense preglacial erosion in the palaeovalley of the Biała Głuchołaska River and, to a lesser extent, due to burial by younger glacial and glaciofluvial sediments.

The proximal facies of the fans consist of massive, sandy to pebbly gravels and gravelly diamictons with high kaolin matrix content. Subangular pebble clasts are common. Graphic mean size (Mz) ranges from 5.0 to 7.3 mm for samples sCH1, sCH2/4 and sG5/4 (Fig. 2). Sorting varies from 4.1 to 4.7, which represents very poorly sorted components according to Folk and Ward (1957). Typically, a high proportion of the matrix consists of silt and clay, with clay contents in the matrix as high as 20–30%. The clasts are composed of up to 85% of milky-white quartz and quartzites.

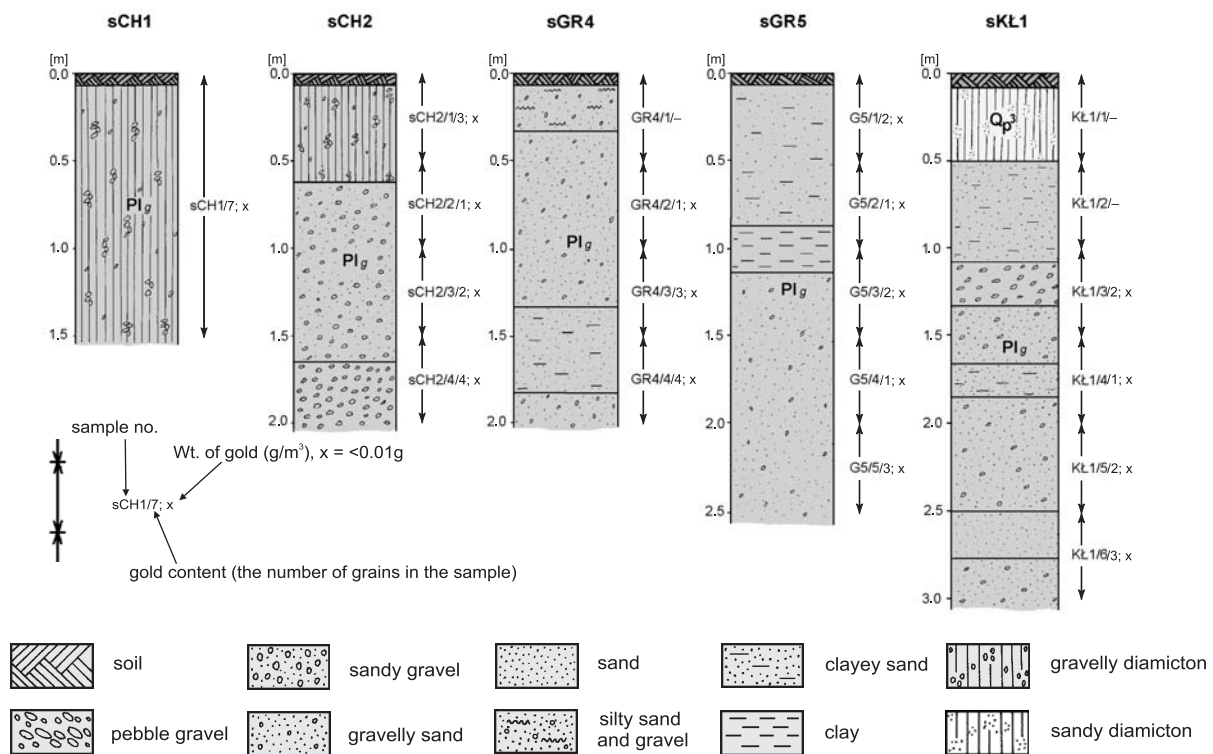


Fig. 2. Schematic outcrop transects of alluvial fan gold-bearing deposits

Q_{p3} — Quaternary (Pleistocene–Saalian), Pl_g — preglacial; the transect locations are shown in Figure 1

Heavy mineral suite consists of opaques (16–54%), zircon (5–28%) and rutile (2–26%). Other major minerals are staurolite, garnet and epidote, with lesser amounts of amphiboles, tourmaline and kyanite. Pebble and heavy minerals composition generally is consistent across the fan (Fig. 2). Poor sorting, large clast sizes and thick bedding in these sediments indicate that they were deposited rapidly by high-energy flows (Wroński, 1975; August *et al.*, 1995; Badura and Przybylski, 1999, 2004).

These deposits form the main piedmont fans gold-bearing horizon containing grades that range between 0.10 g/m³ near the base, to 0.02–0.05 g/m³ in the upper part. Gold grains are fine (<1.0 mm) and have normal size distribution with a mode in the 250–500 µm fraction. A weak skew towards coarser fraction is apparent in some populations. Size distributions with this range and platy form are typical of the East Sudetic placer gold (Wierchowicz, 2002a), although rare placer gold nuggets, up to 1783 g in weight, have been recovered historically (Pošepný, 1895).

For gold exploration, only the proximal facies are of economic interest (Nesterenko, 1977; Boyle, 1979). Gold grains are deposited in channels, while most of the other detrital material is transported further downstream. As in most fluvial placers, gold is enriched along the contact with the bedrock. In the first 1–2 m above this contact, gold grades reach 0.5–1.0 g/m³ and only these horizons were locally mined in the Middle Ages (Rajlich, 1975; Večeřa, 1996).

Sediments of distal alluvial fan facies consist mainly of medium sands and fine gravels. The clasts are composed of milky-white quartz (up to 70%) and quartzites. There are also pebbles of mica schist and, locally, kaolinized granitoids. Occasionally, gravel beds contain clay intraclasts. Gold grade in these sediments is very low (<0.02 g/m³), reaching its maximum in the moderately sorted fine gravel beds. From the exploration prospective, these facies are barren.

PALAEO-BIAŁA GŁUCHOŁASKA AURIFEROUS SEQUENCE

The palaeo-Biała Głuchowska (BG) cross-section can be interpreted, based on the geoelectrical profile, archival boreholes and four new drill cores, as a broad, relatively shallow (~2–2.5 km wide and >8 m deep) channel (Fig. 3).

The borehole sections contain silty to gravelly diamictons, overlain by pebbly to sandy gravels, truncated by tills, interbedded diamictons and mixed clayey to gravelly sand beds (Fig. 4). For the convenience of discussion, the pebbly to sandy gravel sequence of preglacial (Eopleistocene?) age is here informally defined as the White Gravels.

The lithostratigraphic units in the sections from the base to the top include:

- preglacial diamicton, unconformable base (4–18 m thick),
- preglacial White Gravels, erosional base (2.5–6 m thick),
- glacial sediments, erosional base (5–16 m thick),
- post-Elsterian deposits, erosional base (2.5–11 m thick).

The silty to gravelly diamicton (unit a) is a light-coloured, very poorly sorted mixture of gravel, sand, silt and clay, ce-

mented or loosely packed. The clasts are angular and consist of quartz, quartzite and mica schist fragments. This diamicton is related to the preglacial (Eopleistocene?) hill slope process and is underlain unconformably by the light brown to orange Upper Miocene clay bedrock. Gold grade in this unit is low (<0.10 g/m³).

The White Gravels (unit b) truncate silty to gravelly diamicton and comprise light grey, sandy to pebbly gravels with crude horizontal bedding. Graphic mean size (Mz) varies from 2.5 to 5.6 mm for samples — CH1/3, CH1/8, CH2/5 and P1/7 (for sample locations see Fig. 4). Sorting is poor to very poor and ranges from 1.7 (CH1/3) to 3.9 (CH1/8). Clasts are mainly sub-rounded to well-rounded, with less than 5% of angular pebbles. Beneath the sandy gravels is a layer of pebbly gravels, up to 50 cm thick, which covers the erosional surface that truncates diamictons (unit a) (Fig. 4, CH1 borehole). Clayey to gravelly sand lenses, up to 1 m thick, occur in troughs at the erosional surface (Fig. 4, CH3 borehole). Approximately 20–25% of this unit consists of gravelly sand lenses that are 10–30 cm thick. Small pebble lenses occur in the sands. This sequence is interpreted as fluvial palaeochannel sediments. Poor sorting and crude horizontal bedding in gravels are representative of bar deposits in shallow, gravelly, braided river (e.g. Miall, 1977; Schumm, 1985; Leigh *et al.*, 2004). Gravels filling these bedrock palaeochannels contain the gold concentration.

Glacial sediments (unit c) consist mainly of dark grey, coarse-grained diamicton (Elsterian till; Badura and Przybylski, 1996) covering the White Gravels (Figs. 3b and 4). The sediment typically contains 40–55% clasts of Scandinavian limestones in a sandy-silt matrix. This basal till is poorly to moderately indurated and truncates the underlying preglacial White Gravels.

The diamicton can be subdivided into two horizons (Fig. 4, CH1 borehole). The lower horizon is up to 2 m thick, clay-rich, moderately indurated and has a discontinuous cobble pavement at its base. Gold content of this horizon is very low (<0.02 g/m³). The upper horizon is more than 5 m thick, sand- and gravel-rich, poorly indurated and contains well-rounded clasts of Scandinavian limestones. A series of clayey to silty sands is common between the two horizons. It consists of up to 9 m thick, normally graded silt and clayey sand beds that are separated by fine to medium sands of varying thickness. The sand beds are massive and often contain silt-clay laminae with occasional pebbles. Glacial sediments of the Elsterian age are practically barren.

Post-Elsterian deposits (unit d) comprise interbedded, light brown, poorly sorted mixture of silty diamictons, sands and gravels (Fig. 4). The individual beds are 1–3 m thick and consist of sandy gravels, gravelly sands with single cobbles and layers of sandy silts, silts and clays. The fine-grained beds range from a few centimetres to 0.5 m in thickness and have limited lateral extent. This Saalian sequence is capped by Weichselian loesses and loess-like sediments (Badura and Przybylski, 1996), or by Holocene gravelly to clayey diamictons, sands and gravels, sandy silt and clay with organic material (madas) (Fig. 4, P2, CH1–CH3 boreholes).

Petrographic studies of gravels indicate the predominance of local clasts (quartz, quartzites, metamorphic schists and

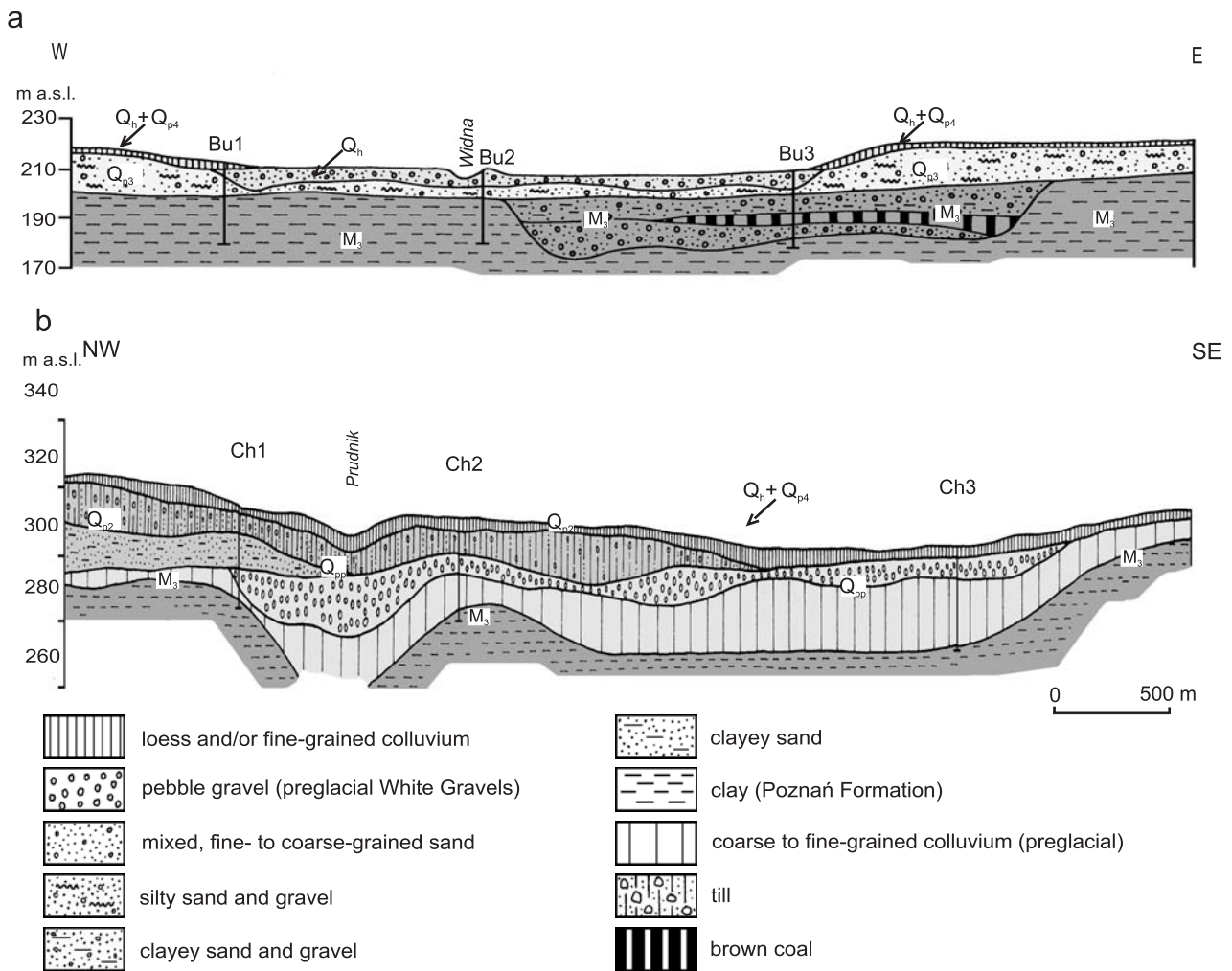


Fig. 3. Geological cross-sections of buried palaeochannels; a — the Widna River; b — the Biała Głuchołaska River

Bu1–3 and Ch1–3 — locations of boreholes with gold-bearing sediments; stratigraphy: Q_h — Holocene, Q_{p4} — Weichselian, Q_{p3} — Saalian, Q_{p2} — Elsterian, Q_{pp} — Eopleistocene?, M₃ — Upper Miocene, location of boreholes are shown in Figure 1

granitoids), although a small admixture of glacially derived rocks is also present (1–5%). Placer gold in this series occurs in gravel and gravelly sand beds. Very low gold concentrations of <0.02 g/m³ were noted, with the maximum concentrations in the fluvial gravelly sands. Diamictons and loess-like deposits do not contain gold.

PREGLACIAL GOLD-BEARING PALAEOCHANNELS

The preglacial development of the bedrock palaeochannel system in the East Sudetic Foreland has been discussed by Wroński (1975), Dyjor (1985, 1987, 1995), Dyjor *et al.* (1978), Wierchowicz and Wojciechowski (1997), Przybylski *et al.* (1998), Badura and Przybylski (1999, 2000, 2004), and Przybylski and Badura (2001). A characteristic feature of preglacial rivers of that region were tectonically-controlled,

frequent changes of the flow directions. The occurrence of deposits of the Biała Głuchołaska River in the far east of the Sudetic Foreland indicates that this river was flowing in the preglacial times much further to the east than it has been assumed before by Wroński (1975) and Dyjor (1985).

The deposits of this river are easily recognizable among other preglacial sediments due to their significant content of staurolite and characteristic petrographic composition of gravels. The Biała Głuchołaska River sediments contain mostly quartz and quartzites. Schists, granitoids and gneisses occur sporadically. The occurrence of preglacial Biała Głuchołaska sediments near Szybowice, Biała and Łącznik (see Badura and Przybylski, 2001, 2004) indicates that this river had been flowing towards the Koźle depression.

Analysis of geoelectrical profiles and available cored boreholes (old and drilled for this project) allows reconstruction of the preglacial river network in the vicinity of Otmuchów–Prudnik (Fig. 1). This study indicated that segments of the preglacial river system have an eastwards trend, parallel to

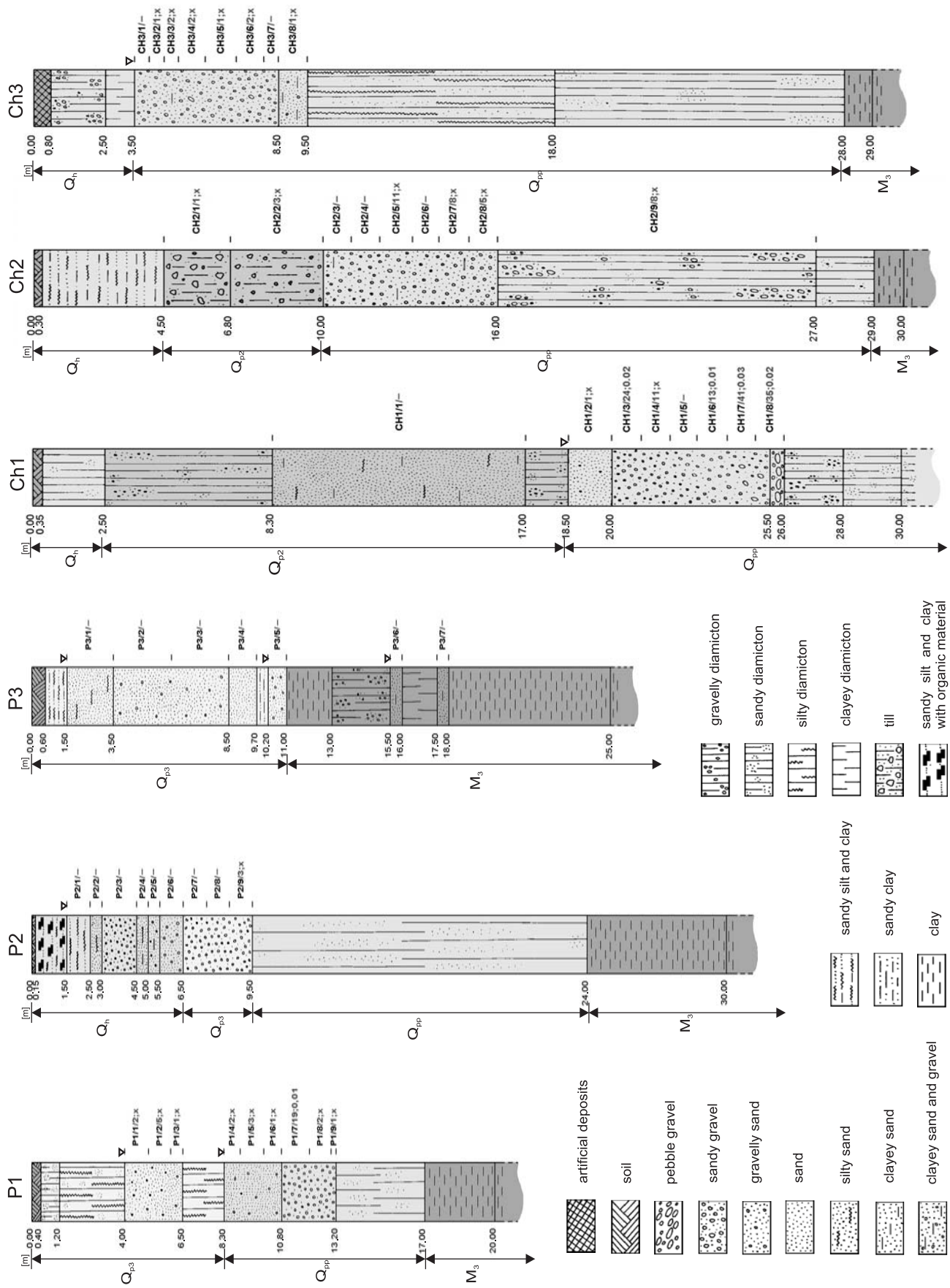


Fig. 4. Schematic drilling transects of the palaeo-Biala Gluchowska gold-bearing sequence and overburden sequence; Prężynka area (P1–P3 boreholes), Charbielin area (Ch1–Ch3 boreholes)

Stratigraphy: Q_h — Holocene, Q_{p4} — Weichselian, Q_{p3} — Saalian, Q_{p2} — Elsterian, Q_{pp} — Pre-Pleistocene, Tr(iM) — Upper Miocene, the transect locations are shown in Figure 1

the regional Osobłoga (Biała Głuchowska) Fault, which cuts across the general north-north-west strike of the East Sudetic metamorphic rocks and the upper Devonian–Carboniferous sedimentary Kulm Complex (Cymerman, 2004).

The age of gold-bearing palaeochannels in the Otmuchów–Prudnik region has not been established because of lack of organic material suitable for dating. Their relative age is defined by correlation with the Elsterian stage till beds (Badura and Przybylski, 1996). The tills are deposited unconformably on the preglacial White Gravel series (Fig. 4, CH1, CH2 boreholes). These gravels are similar to those described in East Sudetes Foreland by Wroński (1975), Przybylski *et al.* (1998), and Badura and Przybylski (1999, 2004) as pre-Elsterian.

The coarse facies of auriferous White Gravel consist mostly of pebbles of quartz and quartzite (80–90%), as well as clasts of mica-schists and granitoids that are locally kaolinized (Fig. 5). These gravels do not contain Scandinavian glacier-transported rocks. Monocrystalline quartz is the most abundant constituent of the sandy facies. The grains are either well rounded or have an euhedral shape with occasional etching pits. Other common components include grains of polycrystalline quartz, sometimes of metamorphic origin, siliceous schist and clasts of other metamorphic rocks. Very low concentrations of other constituents are present locally. These include micas, plagioclase and microcline. The argillaceous detrital fraction is composed primarily of kaolinite and micaceous clays.

The most common heavy minerals are staurolite (20–65%), zircon (3–30%), epidote and garnet. Minor components include opaque minerals, amphiboles, kyanite and titaniferous minerals. Tourmaline, sillimanite and andalusite are present locally.

The White Gravel series is the richest gold-bearing horizon in the studied area. It contains gold grades ranging between 0.37 g/m³ near the base, to <0.10 g/m³ in its upper part (Table 1). The thickness of these sediments varies from 5 to 6 m. The best gold grade is limited to the first 1–2 m above the contact with the bedrock (Fig. 4, CH1 borehole), probably reflecting the sluicing effect (Boyle, 1979).

Field observations and new data obtained from a series of experiments indicate that a number of conditions are necessary

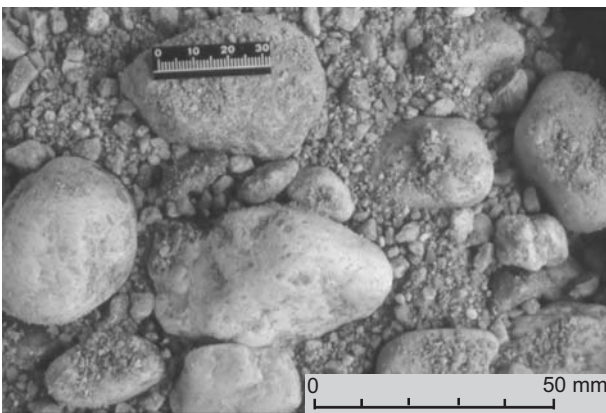


Fig. 5. Coarse-grained facies of the White Gravel series; composed mainly of pebbles of quartz and quartzite; note the rounded grains with etching pits

for heavy minerals to accumulate in coarse-grained alluvium (see Kolesov, 1975; Slingerland, 1984; Reid and Frostick, 1985; Burton and Fralick, 2003). For gold, the most important factor is effective portioning of gold particles into the traction population and quartz sand into the suspension population during flood events that transport the sediment in the river valley. Second factor aiding formation of higher gold grades is pre-concentration, i.e. an enriched, erosional lag up-slope from the area of placer accumulation.

Gold particles from the White Gravels are fine (<1.5 mm), bimodal, being either 150–250 µm or 250–500 µm in size and have a coarse-skewed distribution, which incorporates grains of >1 mm range (Wierchowicz, 2002a). Particles have nearly uniform flat shape.

Silver content, measured in the centre of particles, shows that the principal source for the placer gold were the sedimentary and epimetamorphic covers (weathering zone of polymetallic vein-type deposits) of the Žulova Granitoids and Keprník Massif in Bohemia eroded during the Neogene uplift. After climatic cooling, alluvial fans with gold were extensively reworked, removed and redeposited by the rivers of pre-BG, and their tributaries. This process evolved during Late Pliocene and continued into the Eopleistocene time (palaeobed of the Biała Głuchowska River).

LATE QUATERNARY ALLUVIAL SEDIMENTS

These sediments are exposed on terraces along the Widna and Biała Głuchowska valleys and are known from the borehole sections localized near Buków and Bodzanów (Fig. 1).

Geological cross-section through the northern part of the Widna valley is interpreted basing on the geoelectrical profile, archival boreholes and three new drill cores. The boreholes reveal, in the lower part, more than 30 m of Late Miocene clays with sandy gravels and brown coal interbeds, fluvial sandy gravels and mixed clayey to silty sands of the Saalian age. Post-glacial (Holocene) fluvial channel sands and gravels dominate the upper part (Fig. 6, BU1 and BU3 boreholes).

The Holocene valley of Widna River is shallow (~0.7–1.2 km wide and less than 6 m deep), have a flat cross-section and partly follows the older Miocene valley (Fig. 3a).

The boreholes located near Bodzanów, in the southern part of the Biała Głuchowska valley, intersected >25 m of Late Miocene sandy clays and silty to clayey diamictons, with local sandy brown coal interbeds, covered by more than 4 m of Holocene alluvial deposits including pebbly to sandy gravels and clayey to silty sands (Figs. 1 and 6).

HOLOCENE GOLD-BEARING DEPOSITS

The Holocene terrace facies consist mainly of interbedded sands and gravels. The gravels are poorly sorted (sorting ranges from 3.0 to 3.5), clast-supported and matrix filled (Fig. 7). Pebble beds are 1–2 m thick and have silty to sandy matrix. Cobbles are rare. Silty sand and clay sheets, up to a few centimetres

Gold grades of the main gold-bearing horizons from Otmuchów–Prudnik area

Section	Sample No.	Volume of the sample [m ³]	No. of gold grains in the sample	Wt. of gold [g]	Heavy mineral content [g/m ³]			Gold content [gm ³]	Stratigraphy
					Ferromagnetic fraction	Paramagnetic fraction	Non-magnetic fraction		
Prężynka 1	P1/7	0.093	19	0.01	0.54	474.84	23.66	0.11	Q _{pp}
Charbielin 1	CH1/3	0.082	24	0.02	26.83	153.66	31.71	0.24	Q _{pp}
	CH1/4	0.081	11	<0.01	50.62	283.95	49.38	x	Q _{pp}
	CH1/6	0.086	13	0.01	19.77	154.65	32.56	0.12	Q _{pp}
	CH1/7	0.080	41	0.03	37.50	241.25	46.25	0.37	Q _{pp}
	CH1/8	0.094	35	0.02	30.85	194.68	32.98	0.21	Q _{pp}
Charbielin 2	CH2/5	0.076	11	<0.01	18.42	578.95	6.58	x	Q _{pp}
	CH2/7	0.079	8	<0.01	65.82	762.03	43.04	x	Q _{pp}
	CH2/8	0.074	5	<0.01	82.43	562.16	44.59	x	Q _{pp}
	CH2/9	0.090	8	<0.01	62.22	476.67	14.44	x	Q _{pp}
Bodzanów 1	B1/1	0.090	6	<0.01	52.44	804.44	104.67	x	Q _h
	B1/3	0.081	13	0.01	42.72	1222.96	23.70	0.12	Q _h
	B1/4	0.078	12	<0.01	35.90	997.18	18.46	x	Q _h
	B1/5	0.086	6	<0.01	24.19	793.02	30.00	x	Q _h
	B1/6	0.088	25	0.01	68.18	1352.27	7.50	0.12	Q _h
	B1/7	0.084	17	0.02	73.33	1827.38	30.95	0.24	Q _h
	B1/8	0.040	11	<0.01	139.50	2430.00	35.00	x	Q _h
Bodzanów 2	B2/2	0.070	6	<0.01	50.86	495.71	191.71	x	Q _h
	B2/6	0.086	8	<0.01	72.33	1620.47	14.88	x	Q _h
Buków 1	BU1/1	0.086	8	<0.01	0.58	402.33	65.35	x	Q _h
	BU1/3	0.083	6	<0.01	17.35	369.64	77.83	x	Q _h
	BU1/6	0.070	9	<0.01	0.71	748.57	10.57	x	Q _h
Buków 3	BU3/3	0.084	12	0.01	0.60	391.67	42.14	0.12	Q _h
Charbielin*	sCH1	0.065	7	<0.01	0.92	35.38	26.15	x	Pl _g

x — below 0.01 g/m³; Pl_g — preglacial, Q_{pp} — Eopleistocene?, Q_h — Holocene; * — data from outcrop

thick, occur locally. The lower contact of this unit is sharp and marked by concentrations of small cobbles and pebbles. Occasionally, silt and sandy clay clasts, up to 30 cm in size, occur in the lower part, near the erosional surfaces.

The clasts, 0.5–10 cm in size, are subangular to subrounded and occasionally coated with dark manganese oxides. The clasts are dominated by local rocks and include metamorphic schists, quartzites, quartz and granitoids. Small (1–5%) admix-

ture of glacially derived rocks is also present. Composition of heavy mineral assemblages is variable and consists of garnet (5–45%), staurolite (5–40%) and zircon, with subordinate opaque minerals, amphiboles, rutile, epidote and kyanite. Less common are tourmaline, sillimanite, andalusite and pyroxenes.

Gold enrichment in the alluvial deposits of Widna and Biała Głuchołaska rivers occurs in palaeochannels, in close proximity to the bedrock contact. Particularly, if gravels occur

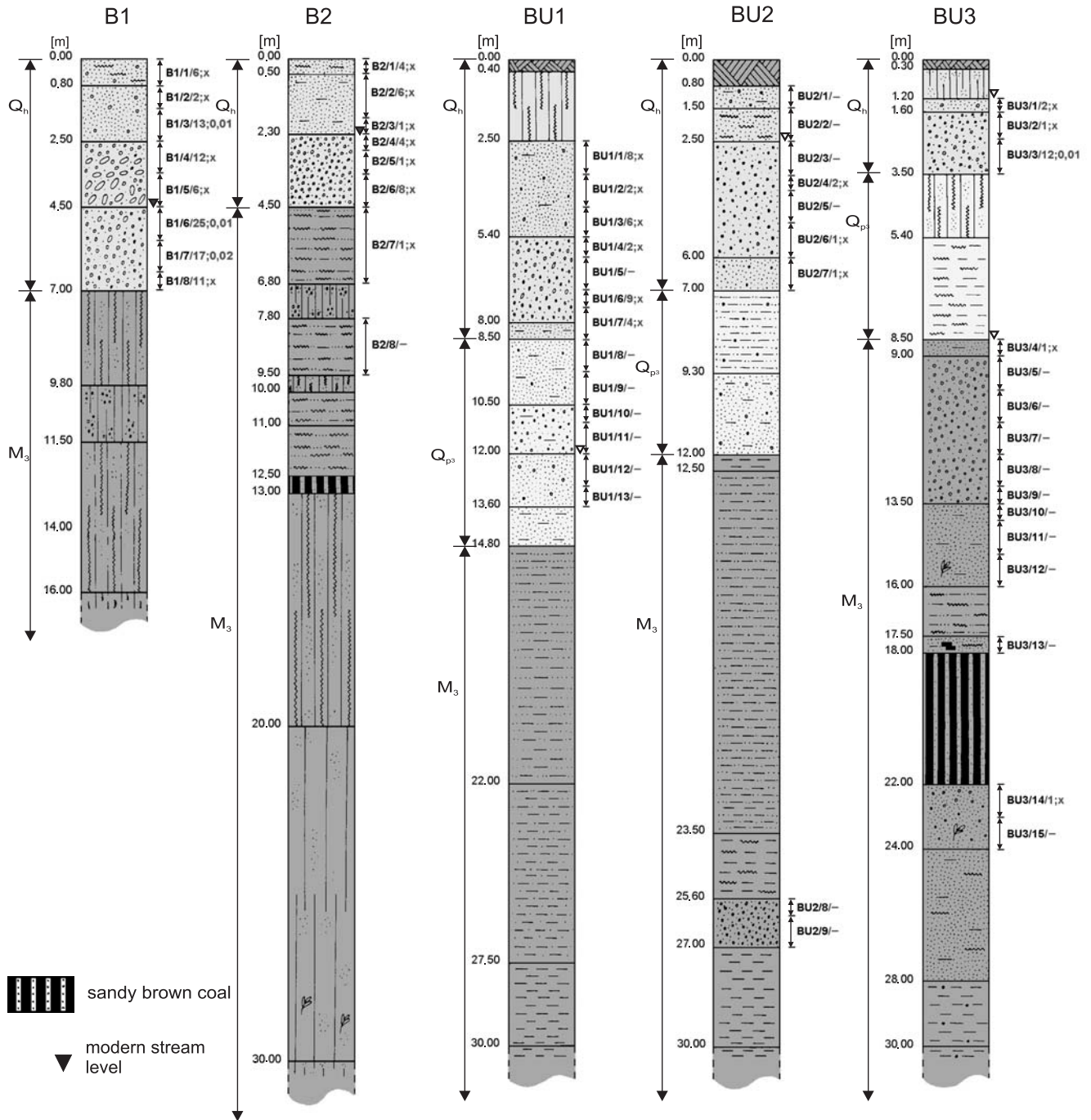


Fig. 6. Schematic drilling transects of the gold-bearing, post-glacial alluvial sediments and underlying barren Miocene sequence

B1, B2 — southern part of the Biała Głuchowska valley; BU1–BU3 — northern part of the Widna valley; the transect locations are shown in Figure 1; for other explanations see Figures 2 and 4

near the current stream level (Fig. 6). Gold grade is generally low ($<0.10 \text{ g/m}^3$), but locally may reach up to 0.24 g/m^3 (Table 1). The thickness of these sediments varies from 2.5 to 7 m. Gold particles are fine, with an average grain-size of $190 \mu\text{m}$. There is a mode of fine grained gold with the same grain-size range as the White Gravels and fan deposits, but a new fine grained ($<150 \mu\text{m}$) mode is developed. Observed increase in the proportion of “sandwich-like” gold particles,

with deformation marks, suggests significant transport and/or palaeoplacer recycling.

The composition of gold grains suggests several possible sources (Wierchowicz, 2001, 2002a). Such potential sources include epimetamorphic rocks surrounding Zlaté Hory Mts. and metamorphic cover of the Žulova Granitoids, in particular the weathering zone of polymetallic veins and other types of mineralization. High fineness of gold grains may reflect grains

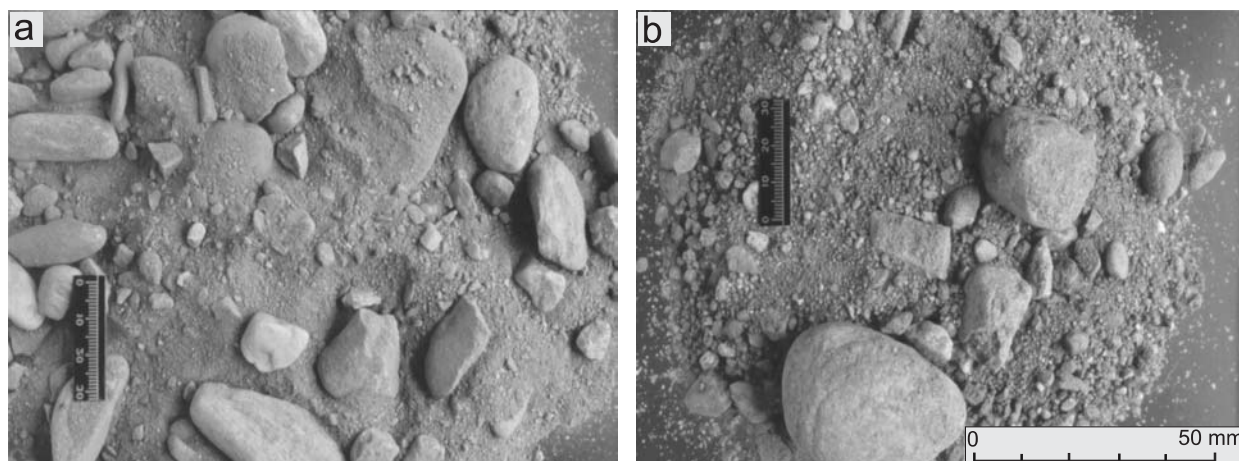


Fig. 7. Poorly sorted, post-glacial alluvial gravels; note the framework clasts composed of metamorphic schists, quartzites and granitoids, and silty to sandy matrix; a — northern part of the Widna valley; b — southern part of the Biała Głucholaska valley

reworked from the preglacial palaeofans and Quaternary gold-bearing strata.

For the most part, the palaeochannels are straighter than the current channels of Widna and Biała Głucholaska rivers. This indicates higher energy fluvial systems. Gold in such stream channel deposits was eroded, hence the grade is lower in comparison with the White Gravels.

REASONS FOR PRESERVATION OF AURIFEROUS ALLUVIA

Fluvial palaeochannels in the vicinity of Otmuchów–Prudnik are broad and shallow. The palaeo-Widna channels are parallel to the regional north-south movement of ice during the Elsterian and Saalian (the last glacial maximum) glaciations, whereas palaeobeds of the Biała Głucholaska River and its tributaries are oriented obliquely (Lindner and Marks, 1995; Badura and Przybylski, 1998; Badura *et al.*, 1998, 2001). Complete removal of the preglacial deposits of the palaeo-Widna and preservation of the palaeochannel gravels of the Biała Głucholaska River is attributed to this setting. Southwards flowing glaciers probably were not able to erode deeply into the bedrock walled, east-trending, palaeo-BG valley. Similarly, palaeochannel gold-bearing deposits in the Cariboo region of central British Columbia and in the Otter Creek area in the north-west British Columbia are preserved along tributary streams oriented obliquely to the former ice-flow direction (Levson and Giles, 1993; Levson and Blyth, 2001).

DEPOSITIONAL MODEL FOR THE AURIFEROUS SEDIMENTS

Today, there are no large primary gold sources proximal to the studied gold-bearing sediments. It is suggested therefore that the most significant primary gold source was the sedimentary and epimetamorphic cover of the Żulova Granitoids and

metamorphic rocks in the Głucholazy region, eroded and removed during the Neogene. A significant content of staurolite among heavy minerals suggests an influx of material from the Jeseník Mts. and Keprník Massif in Bohemia (Badura and Przybylski, 2004).

Gold was liberated from its host minerals and concentrated secondarily in enrichment zones. The Alpine tectonic movements, that uplifted the East Sudetes, enhanced gold transport either as detrital grains or as colloidal solutions (Wierchowicz, 2002*a, b*) in debris that formed alluvial fans along the mountain front.

During a period of prograding cooling, probably during the Early Quaternary (Eopleistocene), piedmont fans with gold were extensively reworked, removed and redeposited by the rivers of pre-BG and their tributaries. Gold-bearing White Gravels were deposited in high energy channels typical of the preglacial environment. Such a type of accumulation persisted until the Elsterian Glaciation, first major glaciation of the region.

After retreating of the Odranian ice sheet, the palaeo-BG has been captured to the north, when the development of its present-day valley started. The river eroded into the older sediments resulting in reworking of gold grains and formation of new deposits characterized by large volume and very low gold grades.

Finally, stream channel gravels were deposited in the Biała Głucholaska and Widna valleys as post-glacial (Holocene) alluvial gravels. These horizons include gold particles mainly recycled into the trunk rivers from the palaeoplacers and basal tills, as well as gold from local primary sources.

EXPLORATION POTENTIAL OF THE REGION

Gravels correlated with the Biała Głucholaska palaeochannel White Gravels occur also in other valleys in the Sudetes and Sudetic Foreland including the Nysa Kłodzka,

Kwisa, Bóbr and Kaczawa valleys (Wroński, 1975; Dyjor *et al.*, 1978; Dyjor, 1987; Speczik and Wierchowicz, 1990, 1991; Badura and Przybylski, 2004). These valleys have high potential for discovery of new auriferous, coarse-grained sediments.

Comparing the geological setting of the Biała Głuchołaska palaeochannel White Gravels with the largely unexplored Nysa Kłodzka palaeochannels between Janowice and Nysa (Przybylski *et al.*, 1998) suggest that there is also high potential for a discovery of gold-bearing, buried channel deposits. The two valleys are geomorphologically similar and both are oriented obliquely to the regional north to south ice-flow direction. Elsterian till deposits cover the preglacial surface in both areas and “white gravels”, stratigraphically equivalent to the Biała Głuchołaska River palaeochannel deposits, underlie the tills in the Nysa Kłodzka valley. Gold-bearing Holocene gravels have been discovered recently in both valleys (Jęczmyk and Wojciechowski, 1994; Muszer and Łuszczkiewicz, 1997).

The valley, downstream from the point where Nysa Kłodzka River changes direction from north-east to easterly, is the area with the best potential for buried gold-bearing palaeochannels (Przybylski *et al.*, 1998). The valley there cuts across the Marginal Sudetic Fault and is oriented obliquely to the regional ice-flow direction, therefore may have escaped deep glacial erosion.

The study of archival borehole sections in the area suggests that there is also potential for buried tributary channel deposits along both sides of the palaeo-BG valley. Gold has been recovered, by mediaeval miners, mainly from the Holocene and Weichselian alluvial deposits of the Biała Głuchołaska and Złoty Potok rivers (Večeřa, 1996) (see Fig. 1), but the possibility of buried channels, tributary to the Biała Głuchołaska palaeochannel, is also indicated at several other sites (Badura and Przybylski, 1999, 2000; Przybylski and Badura, 2001).

North of the palaeo-BG, towards the Nysa Kłodzka valley, the possible palaeochannels are buried by 10–30 metres of glacial and glaciofluvial sediments. There is also potential for buried channel deposits along the south side of the palaeo-BG, where the valley changes direction from east to a southeasterly. The depth of burial of the gold-bearing horizon under till in the lower palaeovalley of this river and the stratigraphy indicate that thick overburden would inhibit exploration along other rivers with high potential for discovery of auriferous sediments in the region.

The geometry of the palaeo-BG valley suggests that locations of potential gold-bearing channel deposits are constrained largely by the geomorphic setting. The broad and deep bedrock palaeochannels oriented obliquely to the regional south ice-flow direction indicate that undiscovered resources of placer gold along the sides the palaeovalley in this area, or in other similar settings in the Sudetes, is considerable. Other, flat and shallow valleys, particularly those oriented parallel to the glacial movement, are likely to be barren. The depth of ice erosion and thick overburden are the main factors limiting location and possible exploitation of the gold-bearing strata.

Shilts and Smith (1986) came to a similar conclusion after a study in the Appalachian Mountains, where it was found that preservation of preglacial placer deposits occurred in valleys oriented transverse to the regional ice-flow direction, while

other deposits were destroyed during glaciation. Similarly, palaeochannel placer deposits of the Klondike Plateau (west-central Yukon) and in the Livingstone Creek area in central Yukon Territory are preserved along tributary streams oriented obliquely to the former ice-flow direction (Duk-Rodkin *et al.*, 2001; Levson and Blyth, 2001).

More work is required to evaluate the placer potential of the Otmuchów–Prudnik region. Presence of areas protected by law, such as Opawskie Mts. Landscape Park, ecological use, meadows, forests and recreational places are also limiting extent of areas prospective for palaeoplacer gold mineralisation, which could be potentially available for future exploitation (Urbańska, 1998).

CONCLUSIONS

The best placer potential for gold in the East Sudetic Foreland lies in the preglacial (Eopleistocene?) drainage system, primarily in palaeochannels of the Biała Głuchołaska River and its tributaries. The preglacial White Gravel series is the richest gold-bearing horizon in the studied area, with gold grades that range between 0.37 g/m³ near the base to <0.10 g/m³ in the upper part. The highest grade occurs in the first 1–2 m above the contact with the bedrock.

Lower gold concentrations occur in Holocene alluvial sediments of the Biała Głuchołaska and Widna rivers. Gold enrichment within the terrace deposits of these rivers is limited to palaeochannels in close proximity to the bedrock contact, particularly if the gravels occur near the modern stream level. Gold grade is generally low, but local enrichments in gravel channels up to 0.24 g/m³ were noted.

Gold concentration is controlled by the ability of the streams to aggradation, pre-concentration and the development of sedimentologic traps, where gold was accumulated during valley erosion. The presence of bedrock-walled valleys is a necessary condition for the development of relatively rich gold-bearing horizons and their preservation. Oblique orientation of the palaeo-BG valley to the regional ice-flow direction probably also prevented the glaciers from eroding deeply into the palaeochannels. The initial glaciation of the Elsterian age played an important role in masking and changing the direction of drainage, and in creation of new channels in the foreland of the East Sudetes.

Comparing the geological setting of the Biała Głuchołaska palaeochannel White Gravels with others largely unexplored regions of the Sudetes suggests that potential for discovery of gold-bearing, buried channel deposits exists also in other areas. The most prospective gravel beds, stratigraphically correlated with the Biała Głuchołaska palaeochannel White Gravels, occur in the valley of Nysa Kłodzka.

In exploration for alluvial gold mineralization in the described region application of geological conditions described in this report could be effective for identifying prospective buried placer targets. Moreover, the geomorphical and geological data from the study area imply that understanding of the local glacial history, as well as the geology of the gold-bearing horizons and their overburden, would be also a useful exploration

tool for buried placer deposits in other glaciated provinces. Placer gold has been recently recovered from at least several sites in the areas where palaeoplacer potential was previously inferred using stratigraphic and geomorphologic criteria (Shilts

and Smith, 1986; Levson and Giles, 1993; Patyk-Kara, 1999; Levson and Blyth, 2001).

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