Acta Geologica Polonica, Vol. 57 (2007), No. 4, pp. 523-537

Placer gold and other economic minerals from the remnants of palaeofan deposits in the foreland of the East Sudetes, Poland

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ABSTRACT:

WIERCHOWIEC, J. 2007. Placer gold and other economic minerals from the remnants of palaeofan deposits in the foreland of the East Sudetes, Poland. *Acta Geologica Polonica*, **57** (4), 523-537. Warszawa.

Gold-bearing palaeofan deposits in the East Sudetic Foreland region are associated with the White Gravel series, which is the richest gold-bearing horizon. The remnants of the White Gravels in the vicinity of Gierałcice and Sławniowice contain between 0.33 g/m^3 Au near the base and <0.05 g/m^3 Au in the upper part. The gold is associated with other heavy minerals, such as Fe-Ti oxides (magnetite, ilmenite, and hematite), zircon and rutile. Concentration of these minerals increases significantly with depth and three-quarters of the total gold is found in the lower half of the palaeofan deposits. The alluvial palaeofan placers were formed by repeated scouring and reconcentration of resistant heavy minerals from a number of sources, including pre-existing placers and bedrock. The gold grains are composed of variable proportions of Au and Ag with trace amounts of Cu, Te and Se. Rims have high gold (>93 wt % Au) and low silver (<6 wt % Ag) contents, whereas cores contain average 85 wt % Au and 14 wt % Ag. Porous gold grains are homogeneous and of high purity (>95 wt % Au). The bedrock source of gold is probably related to quartz veins in Palaeozoic schist and quartzite. There are several local point sources of gold, mainly quartz veins of the Zlatý Chlum Massif. Data presented for the Gierałcice–Sławniowice palaeofan placers may be useful for prospecting and exploration for similar deposits.

Key words: East Sudetes, White Gravels, Palaeofan deposits, Economic heavy minerals, Placer gold.

INTRODUCTION

Investigations of fluvial placer gold and other economic placer mineral deposits concentrate almost exclusively on Early Pleistocene to Holocene sediments, as these contain most of such deposits in the world (BOYLE 1987; STANAWAY 1992; LAVEROV 1997; YOUNGSON & CRAW 1995, 1999; SHILO 2002). The placer deposits are structurally and sedimentologically well understood and provide much information on the processes of their formation. Numerous studies have described Quaternary auriferous alluvia from the Sudetes and its foreland (SPECZIK & WIERCHOWIEC 1991,

WOJCIECHOWSKI 1993, WOJCIECHOWSKI 1994, SPECZIK & WOŁKOWICZ 1995, MUSZER & ŁUSZCZKIEWICZ 1997, WIERCHOWIEC 2002b). Surprisingly, little attention has been given to placer gold from piedmont alluvial fans deposited in the pre-glacial time along the northern margins of the Sudetes (see WIERCHOWIEC & WOJCIECHOWSKI 1997; WIERCHOWIEC 2001, 2002a).

One of the main targets of the present study was detection and evaluation of gold in the preglacial palaeofan of the Sławniowice–Gierałcice area. Recent advances in understanding palaeodrainage in the Sudetic Foreland have led to the development of new models for the landscape evolution of that region (PRZYBYLSKI & *al.* 1998; CZERWONKA & KRZYSZKOWKI 2001; BADURA & PRZYBYLSKI 2004, 2005). Detailed investigations have shown that the gold, which is now contained in Quaternary deposits, is not of Quaternary age, but has a long history of recycling since initial erosion from the bedrock source (WIERCHOWIEC 2002a).

Auriferous formations in most of the world's placer deposits pre-dating the glaciations are discontinuous due to glacial and postglacial erosion (BOYLE 1987, LEVSON & BLYTH 2001). Extensive epigenetic erosion in the Sudetes after Pleistocene glaciations and neotectonic movements is still active, and results in segmentation of such deposits (PRZYBYLSKI 1998). Protection from

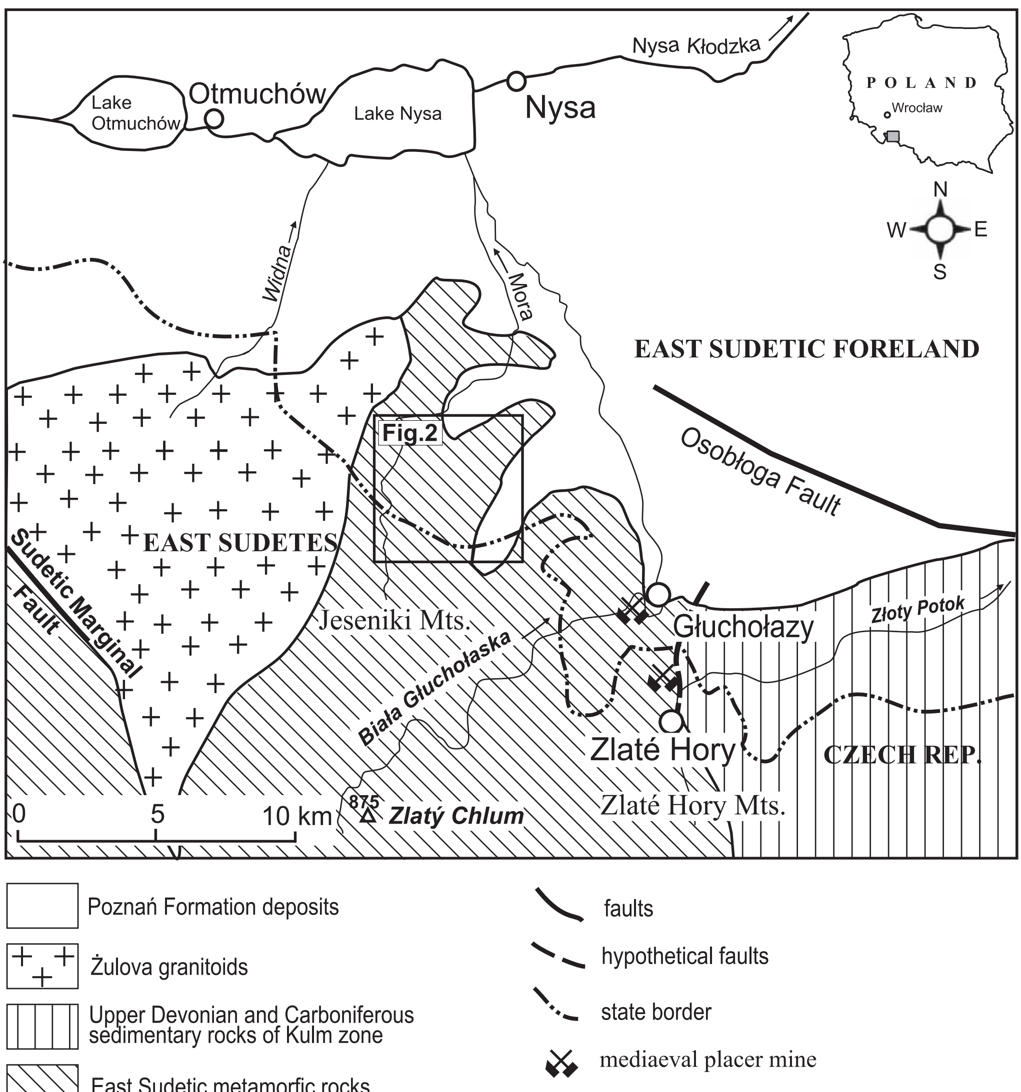


Fig. 1. Simplified geological map of the East Sudetes Mts. and its foreland (without Quaternary cover) showing the location of area studied in relation to the medieval placer mines (modified after GODLEWSKI & WIERCHOWIEC, 2004)

glacial erosion is most common in leeside settings such as the down-ice of large bedrock highs (e.g. Jesenik and Zlaté Hory Mts.) (Text-fig. 1), or in valleys orientated transversely to the regional ice-flow direction (eg. pre-Biała Głuchołaska valley) (WIERCHOWIEC 2006).

This paper investigates and evaluates the potential of palaeofan sediments for placer gold and other economic minerals. Exploration work of the Polish Geological Institute revealed that primary gold in the Eastern Sudetes is confined to amphibolite intercalations within gneisses and quartzites (WOJCIECHOWSKI 1997). On the other hand, gold in quartz veins and placers has been known in that region since the Middle Ages (POŠEPNÝ 1895, GRODZICKI 1972, VEČEŘA 1996).

FIELD AND LABORATORY METHODS

Ten- and 50-litre samples (size depending upon the nature of the sediments) were collected for heavy mineral analysis. Ten samples were taken every 0.5 m from the depth range 2.0-2.5 m in palaeofan outcrops, and nine samples were collected from recent stream deposits (Text-fig. 2). The pebble composition of representative samples from the outcrops studied was determined by documenting the lithology of >200 medium to coarse pebbles (d_I = 0.8-10 cm).

Heavy mineral concentrates were collected using a panning dish and portable sluice box. Great care was taken to save as much of the fine gold as possible, but some extremely fine gold may have been lost. Gold-bearing field samples were reprocessed in the laboratory by repeated careful panning of concentrates from which gold was separated by hand-picking. Gold content was expressed by the number of grains in the sample and by weight, if the gold content was above 0.01 g/m^3.

The laboratory processing, identification of heavy minerals and detailed examination methods of placer gold were described by WIERCHOWIEC (2002a, 2006). The samples were sieved through 250, 125 and 62 micron sieves; the resulting fractions were then dried in an oven at 80°C. For each sample, 300 grains were identified under the microscope in reflected and transmitted light (MANGE & MAURER 1992). Heavy mineral compositions of the gold-bearing concentrates are summarised in Table 1.

In addition, grain size parameters were calculated for ten representative samples according to the procedure of FOLK & WARD (1957).

GEOLOGY OF THE PALAEOFAN SEQUENCE

The occurrences of placer gold and other economic minerals are associated with so-called ‘preglacial’ piedmont fan sediments. These alluvial fan deposits pre-date the Elsterian glaciation and overlie Late Miocene sediments of the Poznań Formation or Palaeozoic metamorphic rocks (Text-fig. 1). The deposits of the piedmont fans is likely to be derived from the Neogene weathering cover of the Sudetes (SAWICKI 1972; DYJOR *& al.* 1978; KRYZA & POPRAWSKI 1987; DYJOR 1995). Although there is no direct dating for the alluvial fan deposits, the transitional relationship with the lithostratigraphic unit commonly known as ‘White Gravels’ suggests a Pliocene–Middle Pleistocene age (ZEUNER 1928; WROŃSKI 1975; DYJOR 1984; BADURA & PRZYBYLSKI 1999, 2004).

The East Sudetes were uplifted during the Alpine Orogeny between the Miocene and Late Pliocene. Following the period of uplifting, the East Sudetes Mts., together with mountain ranges elsewhere in the Sudetes, experienced significant chemical and physical weathering, which generated massive volumes of detrital material (e.g., JAHN 1980; DYJOR 1975, 1995). The transfer of that material through drainage basins during periods of dry, periglacial climate, particularly between the Late Pliocene and Early Pleistocene, resulted in the accumulation of conglomerates, ‘white’ kaolinite clays, clayey sands and gravels within the Zlaté Hory and Otmuchów-Prudnik basins. The total thickness of the sediments in these basins is not known, but limited borehole data suggest thicknesses varying between two and 20 metres (SAWICKI 1972). The deposition of coarse-grained sediment in the Pliocene resulted in the development of piedmont fan systems along the northern margins of the East Sudetes Mts. range (WROŃSKI 1975; DYJOR *& al.* 1978). The fan deposits were strongly eroded and reworked during the pre-glacial and Pleistocene.

Remnants of massive, sandy to pebbly gravels and gravelly diamictons with high kaolin matrix content, interpreted by WIERCHOWIEC (2006) as ‘White Gravels’, are preserved along the northern margins of the Eastern Sudetes in the Sławniowice–Gierałcice area (Text-fig. 2). The palaeofan sequences are locally overlain unconformably by glacial and glaciofluvial sediments, up to 5-6 m thick. The fan surface is largely flat, apart from a 2.0-2.5 metres deep fan trench extending across the north-eastern flank of the fan (see Text-fig. 2, outcrops M1–4).

Mechanical and petrological analysis

The fan deposits described in this paper include a variety of poorly sorted, massive gravels and diamictons deposited mainly by sediment gravity flows. The proximal fan sections (samples:

Sampling site	Sample No.	Volume of the sample [m^3]	Number of gold grains in the sample	Wt. of gold [g]	Heavy mineral content [g/m^3]			Gold content [g/m^3]	Stratigraphy
					magnetic fraction	paramagnetic fraction	non-magnetic fraction		
proximal fan unit (P)	P 1/2	0.010	2	<0.01	113.50	1354.50	123.05	x	Pl_g
	P 1/3	0.020	4	<0.01	121.90	1235.80	125.80	0.02	Pl_g
	P 1/4	0.020	9	<0.01	102.40	789.95	164.00	0.05	Pl_g
	P 1/5	0.050	19	0.01	132.05	876.80	222.60	0.20	Pl_g
	P 2/3	0.020	7	<0.01	124.55	987.60	98.90	x	Pl_g
	P 2/4	0.020	14	<0.01	133.70	1876.90	176.85	0.15	Pl_g
	P 3/3	0.020	3	<0.01	109.75	1675.45	122.70	x	Pl_g
	P 3/5	0.040	17	0.01	112.00	1840.80	165.40	0.25	Pl_g
	P 4/3	0.040	14	0.01	31.50	1230.00	322.80	0.25	Pl_g
	P 4/4	0.030	21	0.01	139.30	1877.85	298.55	0.33	Pl_g
medial fan unit (M)	M 1/3	0.020	3	<0.01	45.50	199.00	67.50	x	Pl_g
	M 2/4	0.020	6	<0.01	76.05	139.50	72.50	0.01	Pl_g
	M 2/5	0.020	9	<0.01	62.10	144.50	23.30	0.05	Pl_g
	M 3/2	0.020	4	<0.01	49.30	178.00	63.70	0.03	Pl_g
	M 3/3	0.020	7	<0.01	79.35	192.70	56.70	0.04	Pl_g
	M 3/4	0.020	9	<0.01	72.35	132.90	117.70	0.07	Pl_g
distal fan unit (D)	D 1/3	0.010	1	<0.01	17.50	99.00	62.50	x	Pl_g
	D 1/4	0.020	2	<0.01	15.00	107.50	74.00	x	Pl_g
	D 2/2	0.010	1	<0.01	3.20	132.50	14.60	x	Pl_g
	D 2/3	0.020	3	<0.01	35.50	156.80	22.50	x	Pl_g
	D 2/4	0.020	2	<0.01	32.50	24.70	19.50	x	Pl_g
stream sediments	1	0.020	5	<0.01	23.30	1827.30	30.95	x	Q_h
	2	0.010	3	<0.01	31.50	1330.00	35.00	x	Q_h
	3	0.010	4	<0.01	24.90	516.25	76.60	x	Q_h
	4	0.010	7	<0.01	50.85	485.70	81.80	x	Q_h
	5	0.020	9	<0.01	35.40	674.80	85.45	x	Q_h
	7	0.020	8	<0.01	27.80	1964.40	40.20	x	Q_h
	8	0.020	2	<0.01	39.30	2021.50	43.20	x	Q_h

x – below 0.01 g/m^3 Pl_g– preglacial, Q_h– Holocene

Table 1. Heavy mineral content with proportion divided between the magnetic, para- and non-magnetic fractions of the gold-bearing samples

P1–4) consist of kaolinite matrix-filled, gravel to large pebble diamictons. Angular and subangular clasts are common. Most beds appear to be ungraded.

Pebbles (0.8-10 cm) are dominated by milky-white quartz (25-55%), quartzite (34-65%), and kaolinised granitoids (2-14%). Milky-white quartz and quartzite are commonly present as angular clasts, while granitoids form subangular ovoid clasts. Minor components comprise mica schist and clay intraclasts. Pebble composition is consistent across the fan.

Poor sorting (3.8 to 4.5), large clast sizes (4.5 to 9.6 mm; samples P1/5, P2/4, P3/5 and P4/4) and thick bedding indicate rapid deposition by high-energy flows. Similar matrix-supported diamictons have been interpreted as debris flow deposits by numerous authors (e.g. WROŃSKI 1975; AUGUST *& al.*, 1995; BADURA & PRZYBYLSKI 1999, 2004; WIERCHOWIEC 2006).

The middle fan sections (outcrops M1–4, Text-fig. 2) consist of sheetflood deposits of coarse sands, gravels and occasional cobbles. Massive gravel beds are also common.

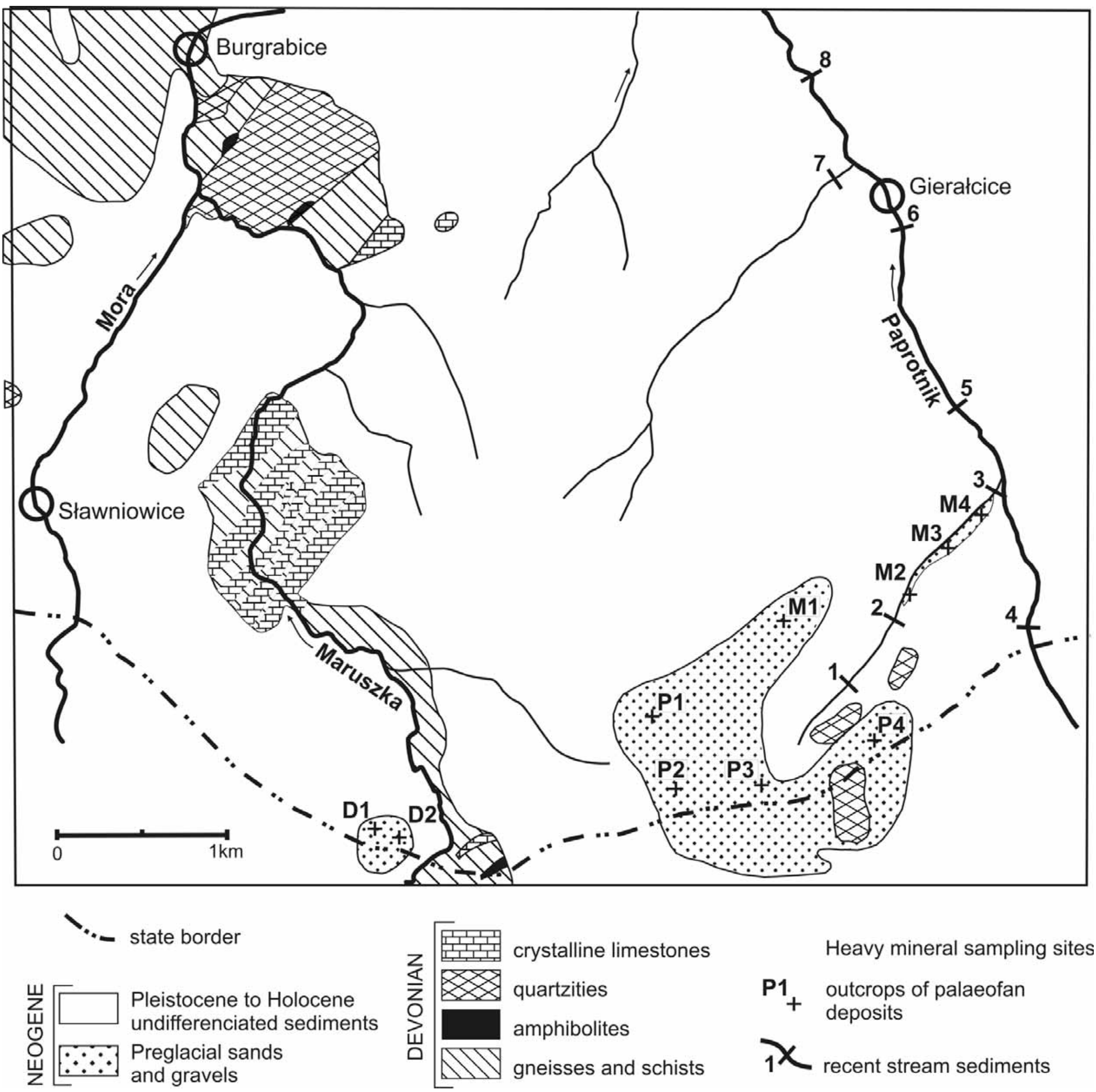


Fig. 2. Geological sketch map of Sławniowice–Gierałcice area (compiled from SAWICKI 1972; BARANIECKI *& al.* 1972) showing the approximate extent of palaeofan deposits and the sampling sites for this study

Graphic mean size varies from 2.2 to 4.6 mm for samples M1/3, M2/5 and M3/4. Sorting ranges from 1.4 to 0.4, indicating poorly to well sorted components. Poor sorting, lack of stratification in the matrix and clast-supported framework, suggest that suspension deposition of the matrix took place simultaneously with traction sedimentation of the gravels. This is consistent with sheetflood deposition, transitional between fluvial gravels and debris flow deposits (BALANCE 1984; BLAIR & MCPHERSON 1994; BLAIR 2000). The clasts are composed of milky quartz (20-45%), quartzite (45-75%) and kaolinised granitoids (5-10%). There are also pebbles of mica schist and gneisses. Occasionally gravel beds contain clay intraclasts.

Sections of the distal fan exposed in the outcrops D1 and D2 (see Text-fig. 2) consist of sheetflood deposits comprising mainly medium sands and fine gravels. Cross-stratified sands and gravels are common in these sequences. They are typically moderately to very well sorted and exhibit trough cross-stratification. The clasts contain up to 90% of quartzites and milky-white quartz, small amounts of siliceous schists, granitoids and gneisses.

HEAVY MINERAL CONCENTRATIONS AND CHARACTERISTICS

Concentrations of gold and other heavy minerals

Concentrations of placer gold and other heavy minerals for a specific palaeofan unit vary both laterally and between stratigraphic levels (pre-glacial and Holocene) (Table 1), being highest in proximal fan deposits and significantly lower in the medial and distal units. In the proximal fan sections heavy mineral concentrations vary from 1056 to 2316 g/m^3. The richest concentrations were found in the south-eastern part of the area (sample P4/4: 2315.7 g/m^3). These sediments, interpreted as debris flow deposits, are the principal gold-bearing horizon, containing Au grades that range between 0.33 g/m^3 near the base to 0.02-0.05 g/m^3 in the upper part (Table 1). Gold grade increases significantly with depth and 70-80% of the total gold is found in the lower half of the palaeofan deposits.

In the middle fan sections, the heavy mineral content varies from 230 to 323 g/m^3. Gold grade in these sediments is low and varies from 0.01 to 0.07 g/m^3 for samples M2/4-5 and M3/2-4. The maximum Au concentration was noted near clay intercalations.

Low heavy mineral concentrations were found in the distal fan deposits. The Au grade in these facies is very low ($<$0.01 g/m^3), with maximum concentration in the moderately sorted, cross-stratified sands and gravels. Similar, very low concentrations of placer gold were found in the stream sediments of the Paprotnik river.

Magnetic fraction

The Fe-Ti oxides dominate the heavy mineral fraction in the sediments (Table 2). Magnetic Fe-Ti oxides and sulphides occur together because sulphides commonly form ‘nucleus-like’ inclusions in the oxides, in particular in magnetite(Pl. 1, Fig. 1).

In this paper, the terms ‘exsolution’ and ‘intergrowth’ are used in a broad sense, for morphological descriptive purposes, and refer to lamellar juxtaposition of two or more Fe-Ti oxide mineral phases. The term ‘magnetite’ includes all isotropic phases including titanomagnetite.

Grains of homogeneous magnetite, most of which are angular to slightly rounded, prevail among the opaque phases. The polyphase grains are more common in the stream sediments of the Paprotnik river (ca. 50%), but they also constitute almost 25 vol. % of the magnetic heavy mineral fraction of the proximal and middle fan units.

The heterogeneous magnetite grains are classified into three groups: (a) grains with magnetite-hematite intergrowths occurring as thin to thick lamellae, orientated parallel to the {111} planes of the magnetite (Pl. 1, Fig. 1); (b) grains with magnetite-ilmenite intergrowths typically represented by relatively thick ilmenite lamellae developed in three directions (Pl. 1, Fig. 2); and (c) ‘nucleus-like’ sulphide inclusions (Pl. 1, Fig. 3). Sulphides are represented by fresh or goethitized pyrite and, in rare cases, by pyrrhotite and chalcopyrite.

Deposits of the distal fans and stream sediments of the Paprotnik river contain a greater proportion (over 20 vol.% and 45 vol.%, respectively) of moderately to well rounded magnetite, while the magnetite is completely absent in the samples from the proximal fans. The distal fan deposits also contain the highest percentage (up to 35 vol. %) of composite magnetic grains with magnetite-hematite haloes (Pl. 1, Fig. 4). Such grains are also found in the heavy mineral fraction from middle fans and in

Holocene stream sediments, but their content does not exceed 15 vol. %. In the proximal fans, only traces of such grains are found.

Paramagnetic fraction

The dominant paramagnetic fraction consists of a coarse fraction (126-250 μm) of garnet (Table 2). It forms up to half of the total volume of the heavy mineral fraction in the Holocene stream sediments of the Paprotnik river. Low concentrations (up to 13.9 vol. %) of garnet occur only in samples from the proximal fans.

Ilmenite, in the form of homogeneous anhedral to euhedral grains, is another common paramagnetic mineral. Its concentration ranges from 5 to 15

Sampling site/number of samples (n)	Minerals	Grain size range: 62–125 µm			Grain size range: 126–250 µm		
		Minimum	Maximum	Average	Minimum	Maximum	Average
proximal fan unit /n=10	Fe-Ti oxides	11.3	53.7	39.4	3.1	47.3	37.3
	Zircon	12.1	27.5	19.6	1.9	22.9	10.7
	Rutile	5.2	19.8	13.1	4.6	17.3	11.3
	Garnets	1.8	10.5	6.4	2.3	13.9	8.9
	Staurolite	0.8	10.3	6.2	0.9	21.6	17.8
	Epidote	1.4	11.2	6.1	0.2	8.2	5.9
	Amphiboles	2.1	6.9	4.9	1.9	10.7	4.7
	Others	3.8	9.3	4.3	2.2	8.8	4.1
medial fan unit /n=6	Fe-Ti oxides	10.4	49.7	35.1	2.7	45.3	34.8
	Zircon	9.9	23.9	18.7	0.7	22.0	9.8
	Rutile	3.4	17.6	11.4	3.3	18.6	10.6
	Garnets	2.1	15.7	9.8	3.3	29.9	13.7
	Staurolite	1.7	13.6	9.2	1.9	23.8	16.9
	Epidote	1.0	9.6	5.4	0.1	7.2	5.8
	Amphiboles	3.4	6.9	4.9	1.9	10.7	5.0
	Others	3.8	12.4	5.5	2.6	7.7	3.4
distal fan unit /n=5	Fe-Ti oxides	8.4	44.6	32.7	2.9	40.3	31.7
	Zircon	10.8	28.7	19.4	0.4	17.7	8.8
	Rutile	3.0	16.1	10.8	2.8	14.7	9.2
	Garnets	3.9	23.1	9.3	2.6	23.1	12.7
	Staurolite	1.5	16.6	6.8	1.2	20.3	14.5
	Epidote	1.8	12.4	7.8	0.1	9.7	7.3
	Amphiboles	2.6	9.8	6.3	0.7	12.5	7.7
	Others	1.2	14.6	6.9	2.8	12.4	8.1
stream sediments /n=8	Fe-Ti oxides	10.9	54.8	28.7	4.5	42.4	25.6
	Zircon	6.8	18.5	11.0	0.2	15.8	8.1
	Rutile	1.3	8.6	4.7	1.8	7.7	4.2
	Garnets	5.8	44.8	29.5	2.9	50.7	26.8
	Staurolite	1.0	26.6	11.2	0.4	22.4	16.7
	Epidote	1.3	8.4	4.6	0.1	7.2	4.1
	Amphiboles	2.9	8.5	5.2	0.7	12.5	7.7
	Others	3.2	12.6	5.1	2.3	15.6	6.8

Table 2. Range and average heavy mineral content (vol.%) of the gold-bearing samples separated as two independent fractions

vol. %, but some deposits of the proximal fans contain higher concentrations (up to 17.5 vol. %). In many cases the ilmenite contains exsolved hematite bands (Pl. 1, Figs 5, 6). In addition to the banded intergrowth, these composite grains display other types of exsolution textures, including thick to thin lamellae, trellis and lenses.

Other Fe-Ti oxide minerals, including hematite, martite (a pseudomorph of hematite after magnetite) and goethite are also present. Hematite (5-10 vol. %) forms irregular subrounded or, rarely, well rounded grains. Variable, but generally high, amounts of martite are present in all samples. In the stream samples, martite reaches 8-10 vol. % of the paramagnetic fraction, mainly as subrounded grains. Goethite is rare in all the sediments sampled.

Staurolite and amphiboles are present in all samples, but their concentrations vary significantly (from 0.4 to 26.6 vol. % and 0.7 to 12.5 vol. %, respectively) (Table 2).

Holocene stream sediment samples show very good positive correlation between the amphibole and epidote contents. Monazite is also present in some samples, its concentration ranging from trace to over 3 vol. %. The concentration of monazite is higher in the non-magnetic heavy mineral fraction.

Non-magnetic fraction

The sediments contain considerable amounts of zircon. Table 2 shows that the zircon contents in the fine fraction (62-125 μm) of proximal fans averages 19.6%, while a concentration of 10.7% occurs in the coarse fraction (126-250 μm). Locally zircon concentrations may reach as much as 28.7% and 22.9% in granular fractions of 62-125 and 126-250 μm, respectively (Table 2).

Most of the zircons comprise transparent, pale yellow, short prismatic crystals with smooth shiny faces. Crystal fragments and long prismatic crystals with bipyramidal terminations are also common (Pl. 1, Figs 7, 8). Rounding of the edges of the zircon crystals is relatively rare, except for Holocene stream sediments, which contain 15 to 17 vol. %. of poorly to moderately rounded zircons. The transparent zircons usually have homogeneous compositions without zoning or inclusions. Only in some long prismatic crystals were opaque and rutile inclusions noted (Pl. 1, Fig. 8).

Comparing the results of this study with other studies of the accessory zircon from the East Sudetic metamorphic rocks and Żulova granitoids (DUMICZ 1961, BARANIECKI *& al.* 1972), it can be concluded that the main source of homogeneous, short prismatic and rounded zircons were the high-grade metamorphic rocks from the northern margin of the Jesenik Mts. Long prismatic zircons with inclusions are derived from granitoids of the East Sudetes. GRODZICKI & MAŁETA (1997) associated the genesis of such morphological populations with high-grade metamorphic complexes and granitoids.

Rutile is the second potentially economic mineral in the non-magnetic fraction. It is present in all samples in concentrations that vary between 3.0 and 19.8 vol. % (fine fraction, proximal fans). In some Holocene stream sediments the rutile content decreases to trace values (Table 2).

Rutile occurs as elongated, rounded brown-red grains, commonly forming prismatic crystals with weakly developed bipyramidal faces. In the palaeofans unit and in the recent stream sediments rutile shows positive correlation with zircon and monazite.

The distribution of monazite in the non-magnetic fraction is very erratic. In proximal and mid fan sequences it represents 1 to 5 vol. %, while the distal fan sequence and the Holocene sediments of the Paprotnik river contains no monazite.

The non-magnetic fraction also contains kyanite, tourmaline, andalusite, sillimanite, zoisite and topaz. However, the occurrences of these minerals are sporadic and their concentrations are mostly low. Only in the coarse fraction of some samples from the Holocene stream sediments did kyanite reach concentrations of 5 to 10 vol. %. There is a positive correlation between kyanite, andalusite and sillimanite.

Placer gold

Physical features of the placer gold

The placer gold is generally bright yellow and fine grained, usually falling into the 150-250 μm and 250-500 μm size fractions. The largest gold grain found has a diameter of 1.5 mm. The weight of individual grains ranges from about 1.2 mg to about 0.02 mg. Such a size distribution and morphology of gold grains is typical of the East Sudetic placer gold (WIERCHOWIEC 2002a).

The grains from proximal fans are morphologically and texturally similar to grains from other palaeofan units and are mostly discoidal to irregular in shape. Gold particles vary from rough-surfaced and irregularly shaped, to relatively smooth-surfaced and slightly to moderately flattened with round to oblong shapes. Some of the grains are deformed (Pl. 2, Figs 1-4).

The larger, knobby-shaped grains commonly contain fine-grained rounded to angular quartz detritus and less commonly small specks of gold within indentations along the grain margins (Pl. 2, Figs 7, 8). Many of the gold grains carry bright zones of fine clayey material within pits and cavities (Pl. 2, Fig. 1).

Some of the platy shaped grains are composed of two or more gold grains, with or without detrital quartz particles, forming sandwich-like structures (Pl. 2, Figs 2a, 4). Rare composite grains of goethite sandwiched between two smooth-surfaced, flat gold grains were also noted (Text-fig. 3). Despite this, however, cavities and fold re-entrants on many grains preserved abundant evidence of worm-like or 'spongy' secondary gold (Pl. 2, Fig. 1), similar to that described by KRUPP & WEISER (1992) and WIERCHOWIEC (2002a).

These aggregates of secondary gold are highly porous accumulations that grow on any substrate, including the surface of primary gold (WILSON 1984). Such a spongy gold is a common supergene product of the *in situ* breakdown of auriferous colloids. The structure of 'new' gold aggregates depends on the rate of growth. Rapid accretion results in a loose, spongy form, whereas slow accretion produces more massive 'worm-eaten' forms (SPECZIK & WOŁKOWICZ 1995).

Most grains of gold occurring in the stream sediments of the Paprotnik river have flattened oval cross-sections. Gold particles with bent or crushed edges are common. Elongated, veiny and amoeboid forms are rare. On the surfaces of the grains, there are numerous furrows, scratches and depressions commonly filled with other minerals, usually quartz or clay minerals. Most grains preserve evidence of having been folded and/or hammered during transport (Pl. 2, Figs 5, 6). Sometimes such grains form structures resembling a sandwich. These textural features are typical of grains that have undergone significant fluvial transport (e.g., GIUSTI 1986; YOUNGSON & CRAW 1993, 1995, 1999; WIERCHOWIEC 2002a).

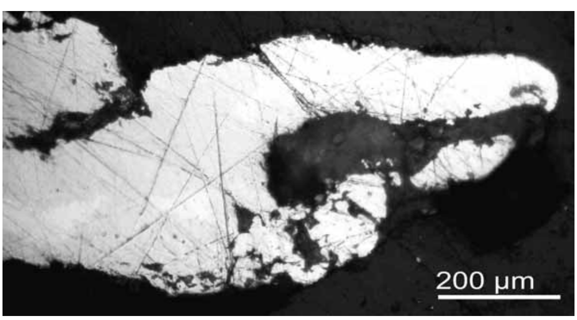


Fig. 3. Reflected light photomicrograph showing a composite grain of goethite sandwiched between two gold grains

Back-scattered electron images of representative placer gold particles are shown in Plate 3. Most of the grains are compositionally inhomogeneous, comprising one or more cores (dark grey) and the pore-rich rim (light grey), and contain round, irregular or elongate pits generally 10 to 50 μm in diameter (Pl. 3, Figs 1-6). In some cases, the pits are connected to the rim through narrow constrictions (Pl. 3, Figs 5, 6) and high fineness gold coats the insides of embayments.

The knobby-shaped particles, in particular, show complex grain-boundary geometry and a characteristic sponge-like internal structure (Pl. 3, Fig. 7). The 10 to 200 μm-thick rims of these grains consist almost entirely of alternating convex and concave surfaces. The convex portions range from gentle curves to rounded protuberances, whereas the concave areas range from slight indentations to deep embayments.

A few grains contain features such as Ag-poor (light grey) tracks or multiple gold-rich zones (Pl. 3, Fig. 8), which could be a consequence of welding the smaller particles (see EYLES 1995). Microprobe investigations of 'welded', intermediate gold identifies almost pure gold (Table 3).

Composition of the gold grains

Seventy microprobe analyses were completed (Table 3), with the number of analyses per grain ranging from two on the smallest particle to 10 on the compositionally inhomogeneous grains. About 75% of the analyzed points were located in cores because these are least affected by supergene leaching and the alloy composition of the gold grains cores reflects a hypogene source of gold (MANN 1984, CHAPMAN & *al*. 2000, CHAPMAN & MORTENSEN 2006).

The gold grains consist of variable proportions of gold and silver (Table 3). Rims typically have high gold (>92.8 wt % Au) and low silver (<5.8 wt

% Ag) contents, whereas cores contain less gold (average 84.8 wt % Au) and more silver (average 14.1 wt % Ag). Little difference is evident in the composition of placer gold from the different sampling sites. Analyses of grain cores show that almost all the cores are alloys of gold and silver, with Cu, Te and Se occurring as trace amounts.

Three distinct categories of gold grains can be distinguished: (1) Ag-poor cores (<20 wt % Ag), mantled by high purity Au (>92.8 wt % Au) thin rims (Pl. 3, Figs 1, 2).

(2) Ag-rich cores (up to 46.8 wt % Ag) that show a relatively dull appearance in the BSE images. These grains are electrum. In some cases, Ag-rich domains (>20 wt % Ag) can be clearly distinguished by their contrast in brightness (Pl. 3, Figs 3–6).

(3) High fineness gold (>95 wt % Au) with characteristic sponge-like internal structure. Dark grey Ag-rich areas and an outer high-purity Au rim are absent (Pl. 3, Fig. 7).

DISCUSSION

Scaning electron microscope observations and X-ray microprobe analyses of the gold grains from the palaeofan deposits and stream sediments indicate that the particles have similar physical and chemical characteristics. However, there are evident differences in the morphology of gold grains from the different sampling sites. The grains from distal palaeofan deposits and stream sediments of the Paprotnik river have morphological and textural features (significant flattening, folding and microtools marks) typical of distal fan placer gold.

The gold is associated with other resistant heavy minerals such as Fe-Ti oxides (magnetite,

Sampling site/number of analyses (*n*)	Metals detected	Core/intermediate*			Rim		
		Minimum	Maximum	Average	Minimum	Maximum	Average
proximal fan unit /*n*=30	Au	57.76	98.20*	83.77	94.17	99.69	96.3
	Ag	0.68*	40.75	14.89	b.d. (3)	5.78	3.13
	Cu	b.d. (4)	1.08	0.46	b.d.(5)	0.54	0.23
	Te	b.d. (3)	0.99*	0.67	b.d. (4)	0.92	0.21
	Se	b.d. (4)	0.31	0.21	b.d. (5)	0.29	0.13
medial fan unit /*n*=20	Au	54.71	97.46	85.76	94.17	99.23	96.82
	Ag	4.76	43.89	13.36	b.d. (2)	3.99	2.65
	Cu	b.d. (2)	0.87	0.39	b.d. (2)	0.33	0.19
	Te	b.d. (3)	0.79	0.23	b.d. (1)	0.92	0.21
	Se	b.d. (1)	0.31	0.26	b.d. (2)	0.3	0.13
distal fan unit /*n*=10	Au	59.87	96.74	86.23	95.21	98.77	97.32
	Ag	6.43	38.71	12.94	b.d. (1)	3.41	2.06
	Cu	b.d. (2)	0.76	0.31	b.d. (2)	0.32	0.17
	Te	b.d. (1)	0.54	0.28	b.d. (1)	0.71	0.32
	Se	b.d. (2)	0.39	0.24	b.d. (2)	0.3	0.13
stream sediments /*n*=10	Au	51.74	90.78	83.61	92.84	97.52	96.77
	Ag	3.91	46.82	15.43	b.d. (2)	3.99	2.54
	Cu	b.d. (2)	0.71	0.32	b.d. (1)	0.34	0.19
	Te	b.d. (2)	0.44	0.37	b.d. (2)	0.52	0.34
	Se	b.d. (3)	0.35	0.27	b.d. (1)	0.35	0.16

Numbers in brackets refer to number of analyses in which Au, Ag, Cu,Te and Se were below detection; b. d. = below detection limit

Table 3. Variation in the composition (wt %) of the gold grains from the Sławniowice–Gierałcice area, East Sudetes

ilmenite, hematite, martite and goethite), zircon, rutile, garnet, kyanite, tourmaline, andalusite, sillimanite, zoisite and topaz. The Fe-Ti oxides, which are the dominant minerals of the heavy mineral fraction, carry unique petrographic fingerprints that indicate a bedrock source of placer gold.

Intergrowths of ilmenite in hematite and/or hematite in magnetite, similar to those described in this study, are commonly seen in detrital opaque Fe-Ti oxide minerals derived from granitoid batholiths (BASU & MOLINAROLI 1989, GRIGSBY 1990). According to these authors, even if the primary s minerals are altered during weathering and diagenesis after deposition, the textural patterns of the intergrowths are still very indicative of their provenance. RIEZEBOS (1979) concluded that grains with preserved intergrowths are more commonly derived from igneous, rather than from metamorphic source rocks.

Zircon provides another valuable tool for indicating provenance. The results of this study, as well as study of accessory zircon from the metamorphic complex in the Jesenik Mts (DUMICZ 1961, BARANIECKI *& al.* 1972, GRODZICKI & MAŁETA 1997), indicate that the main source of the zircon (and consequently some of the gold-bearing sediments) consisted of high-grade metamorphic rocks from the northern margin of the Jesenik massif.

High gold concentrations are common in beds that directly overlie clay-rich sediments, probably because the clays inhibit erosion and act as a trap for gold particles. In the study area, the palaeofan gold-bearing gravels directly overlie the silts and clays of the Poznań Formation. At many prospect sites, clay beds can be used as an indicator of possible overlying gold-bearing units, as well as a stratigraphic marker for following the most auriferous strata (LEVSON & GILES 1993).

Various mechanisms have been proposed to account for the increase in the grades of gold and other heavy economic minerals near the bedrock (BOYLE 1987, LAVEROV 1997, SHILO 2002). The grade of heavy minerals significantly increases with depth and three-quarters of the total gold is found in the lower half of palaeofan deposits. These ‘pay streaks’ are probably generated by the sluicing effect. High-energy flows have eroded the former auriferous sediments carrying deposits further downstream. This action concentrates gold grains that lag behind. As a result of occasional flooding, gold accumulates in the deepest parts of the fan sediments. The formation of the pay streaks assumes a ‘sluicing effect’ of the whole sediment column during important flows. The sluicing effect, however, can only affect the deposits of a single sedimentary cycle and not that of the entire sedimentary sequence. VOGEL *& al.* (1992) conducted numerical experiments to determine the position of gold particles in a placer depository. The model predicted that, for heterogeneous sediment, the grain size of the heavy minerals was the main controlling factor influencing dispersion. It asserted that coarse gold particles would be distributed in the proximal part of the system, while fine-grained gold would be depleted in proximal locations but would be concentrated further downstream (in alluvium).

Textural, morphological, and geochemical evidence indicates that the main part of gold mineralization formed as quartz vein-hosted deposits rather than in the placer environment. The coarsest placer gold occurs together with rounded clasts, which indicates transport. Quartz occurs as fine-grained detritus within the gold, together with microscopic file-dust like pieces of gold within cavities and on the surface of the larger gold particles. Some of the detrital material is lodged within straight-shaped cavities. The larger particles are commonly composed of two or more aggregated gold grains.

The internal structure and chemical composition of the gold grains, as measured in the inner part of the particles, point to several possible Au sources: 1) sedimentary and epimetamorphic covers of the Żulova granitoids, which were completely eroded during progressive Neogene uplift; 2) stockwork or vein Au mineralization from the Zlaté Hory and Zlatý Chlum deposits; and 3) gold grains from reworked pre-existing placers.

Minor metamorphogenic auriferous quartz veins (Zlatý Chlum) and polymetallic vein-type deposits (Zlaté Hory) are known from the East Sudetes (Text-fig. 1). Gold from the Zlaté Hory and Zlatý Chlum contains between 12 and 21 wt % Ag (BERNARD 1991a, b). In contrast, the purity of some gold grains from the palaeofan series is up to 97.5 wt %.

These gold particles are compositionally homogeneous and do not have cores of contrasting composition. Selective dissolution – reprecipitation process during the Neogene weathering of the Sudety Mts is probably responsible for such unusually high purity of the gold. During this process most of the silver was removed by acidic solutions, while the gold precipitated. Grains derived from such weathering profiles usually have a very high fineness and exhibit no zonation in chemical composition (MANN 1984, BOYLE 1987).

CONCLUSIONS

Alluvial palaeofan placers of the Sławniowice–Gierałcice area were formed by scouring and reconcentrating gold from a number of sources including pre-existing placers and bedrock. Gold in palaeofan deposits pre-dating the Elsterian glaciation occurs in thinly interbedded, poorly sorted debris flow deposits and better sorted fluvial gravel and sands. Gold distribution in palaeofans is uneven and its concentrations are generally lower than in stream sediments due to the greater abundance of debris-flow deposits and the relative lack of persistent channeling.

The bedrock source of gold in the study area is likely to be related to quartz veins in Palaeozoic metamorphic rocks (e.g. Zlatý Chlum, Czech Republic). The high-silver, non-porous and massive gold grains indicate a metamorphic stockwork or vein source. Porous pure gold grains with Au content >95 wt % were probably derived from reworked pre-existing placers or were formed during the Neogene weathering.

Many Pliocene and Early Pleistocene palaeofan systems in the Sudetes Mts. were areally extensive and contained some gold concentrations; further exploration for remnants of these deposits is warranted in several other areas of the Sudetes, including the pre-Bóbr and pre-Kaczawa palaeofans (BADURA & PRZYBYLSKI 2004). In addition, gold is often reconcentrated into younger fluvial deposits that unconformably overlie preglacial fan gravels, making them also attractive exploration targets.

REFERENCES

AUGUST, C., AWDANKIEWICZ, M. & WOJEWODA, J. 1995. Tertiary basaltoids, volcanoclastics and sedimentary deposits in the eastern part of the Fore-Sudetic Block. *In*: S. CWOJDZIŃSKI (*Eds*), Przewodnik 66 Zjazdu PTG "Geologia i ochrona środowiska bloku przedsudeckiego. 50 lat polskich badań geologicznych na Dolnym Śląsku", pp. 241-254. Wrocław.

BADURA, J. & PRZYBYLSKI, B. 1999. Pliocene to Middle Pleistocene fluvial series in the East Sudetic Foreland. Quaternary Studies in Poland, Special Issue, 227-233. Poznań.

BADURA, J. & PRZYBYLSKI, B. 2004. Evolution of the Late Neogene and Eopleistocene fluvial system in the Foreland of Sudetes Mountains, SW Poland. *Annales Societatis Geologorum Poloniae*, **74**, 43-61.

— & — 2005. Application of digital elevation models to geological and geomorphological studies – some examples. *Przegląd Geologiczny*, **53** (10), 977-983.

BALANCE, P.F. 1984. Sheet-flow dominated gravel fans of the nonmarine middle Cenozoic Simmler Formation, central California. *Sedimentary Geology*, **38**, 337-359.

BARANIECKI, L., BEREZOWSKA, B. & MORAWSKI, T. 1972. Objaśnienia do Szczegółowa mapy geologicznej Sudetów w skali 1 : 25 000, arkusz Kijów. *Państwy Instytut Geologiczny*; Warszawa.

BASU, A. & MOLINAROLI, E. 1989. Provenance characteristics of detrital opaque Fe–Ti oxide minerals. *Journal of Sedimentary Petrology*, **59**, 922-934.

BERNARD, J.H. 1991a. Lower Carboniferous (?) metamorphogenic Au stockwork mineralization in pre-Devonian metamorphic rocks (type Zlatý Chlum). *In*: J.H. BERNARD (*Eds*), Empirycal type of ore mineralisations in the Bohemian Massif, pp. 60-61. Prague.

— 1991b. Devonian to Carboniferous metamorphic stockwork or vein Au mineralization, partly overlapping the Devonian metamorphic stratiform Fe-Cu-Zn-Pb-(Au) sulfide mineralization (type Zlaté Hory-West). *In*: J.H. BERNARD (*Eds*), Empirycal type of ore mineralisations in the Bohemian Massif, pp. 58-59. Prague.

BLAIR, T.C. 2000. Sedimentology and progressive tectonic unconformities of the sheetflood-dominated Hell's Gate alluvial fan, Death Valley, California. *Sedimentary Geology*, **132**, 233-262.

BLAIR, T.C. & MCPHERSON, J.G. 1994. Alluvial fans and their natural distinction from rivers based on morphology, hydraulic processes, sedimentary processes, and facies. *Journal of Sedimentary Research*, **64**, 451-490.

BOYLE, W.R. 1987. Gold: the history and genesis of deposits. 1-675. *Van Nostrad Reinhold Publication*; New York.

CHAPMAN, R.J., LEAKE, R.C. & MOLES, N.R. 2000. The use of microchemical analysis of alluvial gold grains in mineral exploration: experiences in Britain and Ireland. *Journal of Geochemical Exploration*, **71**, 241-268.

CHAPMAN, R.J. & MORTENSEN, J.K. 2006. Application of microchemical characterization of placer gold grains to exploration for epithermal gold mineralization in regions of poor exposure. *Journal of Geochemical Exploration*, **91**, 1-26.

CZERWONKA, J.A. & KRZYSZKOWKI, D. 2001. Preglacial (Pliocene–Early Middle Pleistocene) deposits in Southwestern Poland: lithostratigraphy and reconstruction of drainage pattern. *In*: D. KRZYSZKOWSKI (*Eds*), Late Cainozoic Stratigraphy and Palaeogeography of the Sudetic Foreland, pp. 147-195, Wrocław.

DUMICZ, M.1961. Budowa geologiczna metamorfiku Sudetów Wschodnich w okolicy Sławniowic. *Zeszyty Naukowe Uniwersytetu Wrocławskiego*, **6** (b), 1-12.

DYJOR, S. 1975. Late Tertiary tectonic movements in the Sudety Mts. and Fore-Sudetic Block (in Polish with English summary). *In*: W.C. KOWALSKI (*Eds*), Recent and neotectonic crustal movements in Poland. Materiały I-go Krajowego Sympozjum, **1**, pp. 121-132.

— & 1984. Wykształcenie i wiek formacji trzeciorzędowej Opolszczyzny. *Materiały i Studia Opolskie*, **26** (52/53), 33-58.

— & 1995. Evolution of the Cainozoic on the Fore-Sudetic Block. *In*: S. CWOJDZIŃSKI (*Eds*), Przewodnik 66 Zjazdu PTG "Geologia i ochrona środowiska bloku przedsudeckiego. 50 lat polskich badań geologicznych na Dolnym Śląsku", pp. 29-40. Wrocław. [*In Polish with English summary*]

DYJOR, S., DENDEWICZ, A., GRODZICKI, A. & SADOWSKA, A. 1978. The Neogene and old-Pleistocene sedimentation in the Paczków and Kędzierzyn graben zones, southern Poland. *Geologia Sudetica*, **13** (1), 31-66. [*In Polish with English summary*]

EYLES, N. 1995. Characteristics and origin of coarse gold in Late Pleistocene sediments of the Cariboo placer mining district, British Columbia, Canada. *Sedimentary Geology,* **95**, 69-95.

FOLK, R.L. & WARD, W.C. 1957. Brazor River bar: a study of significance of grain size parameters. *Journal of Sedimentary Petrology*, **27** (1), 3-26.

GIUSTI, L. 1986. The morphology, mineralogy, and behavior of fine-grained gold from placer deposits of Alberta: sampling and implications for mineral exploration. *Canadian Journal of Earth Science,* **23**, 1662-1672.

GODLEWSKI, A. & WIERCHOWIEC, J. 2004. Detrital gold and others heavy minerals in alluvial deposits of Maruszka Stream near Burgrabice (East Sudety Mts., SW Poland). *Przegląd Geologiczny*, **52**, 216-222. [*In Polish with English summary*]

GRIGSBY, J. 1990. Detrital magnetite as a provenance indicator. *Journal of Sedimentary Petrology*, **60**, 940-951.

GRODZICKI, A. 1972. Petrologia i mineralogia piasków złotonośnych Dolnego Śląska. *Geologia Sudetica*, **6**, 233-288.

GRODZICKI, A. & MAŁETA, D. 1997. Piaski złotonośne okolic Jeleniej Góry. *In*: A. MUSZER (*Eds*), Metale szlachetne w NE części Masywu Czeskiego i w obszarach przyległych. Geneza, występowanie, perspektywy, pp. 112-115, Wrocław.

JAHN, A. 1980. Główne cechy i wiek rzeźby Sudetów. *Czasopismo Geograficzne*, **51**, 129-154.

KRUPP, R.E. & WEISER, T. 1992. On the stability of gold-silver alloys in the weathering environment. *Mineralium Deposita*, **27**, 268-275.

KRYZA, J. & POPRAWSKI, L. 1987. An attempt of reconstruction of the Pleistocene buried valleys in SW Poland. *In*: A. JAHN & S. DYJOR (*Eds*), Problemy młodszego neogenu i eoplejstocenu w Polsce, pp. 137-145. Wrocław. [*In Polish with English summary*]

LAVEROV, N.P. 1997. Placer Deposits of Russia and other CIS Countries. *In*: N.G. PATYK-KARA (*Ed*s), Mineralogeny of Placers, Geological and Commercial Types and Development of Raw Material Base, pp. 1-23. Moscow. [*In Russian*]

LEVSON V.M. & BLYTH H. 2001. Formation and preservation of a Tertiary to Pleistocene fluvial gold placer in northwest British Columbia. *Quaternary International*, **82**, 33-50.

LEVSON, V.M. & GILES, T.R. 1993. Geology of Tertiary and Quaternary gold-bearing placers in the Cariboo region, British Columbia. *British Columbia Ministry of Energy, Mines and Petroleum Resources Bulletin*, **89**, 1-202.

LOEN, J.S. 1995. Use of placer gold characteristics to locate bedrock gold mineralization. *Exploration and Mining Geology*, **4**, 335-339.

MANGE, M.A. & MAURER, F.W. 1992. Heavy Minerals in Colour. *Chapman and Hall*; London.

MANN, A.W. 1984. Mobility of gold and silver in lateritic weathering profiles: Some observations from Western Australia. *Economic Geology*, **79**, 35-49.

MORTON, A.C. & HALLSWORTH, C.R. 1994. Identifying provenance-specific features of detrital heavy mineral assemblages in sandstones. *Sedimentary Geology*, **90**, 241-256.

MUSZER, A. & ŁUSZCZKIEWICZ, A. 1997. Występowanie złota w osadach Białej Głuchołaskiej i Złotego Potoku (Głuchołazy-Jarnołtówek). *In*: A. MUSZER (*Eds*), Metale szlachetne w NE części Masywu Czeskiego i w obszarach przyległych. Geneza, występowanie, perspektywy, pp. 133-138, Wrocław.

POŠEPNÝ, F. 1895. Das Goldvorkommen Böhmens und der Nachbarllnder. *Archive Praktische Geologie*, *2*, 1-484.

PRZYBYLSKI, B. 1998. Late Quaternary evolution of the Nysa Kłodzka river valley in the Sudetic Foreland, southwestern Poland. *Geologia Sudetica*, **31** (2), 197-212.

PRZYBYLSKI, B., BADURA, J., CZERWONKA, J., KRZYSZKOWSKI, D., KRAJEWSKA, K. & KUSZELL, T. 1998. The preglacial Nysa Kłodzka fluvial system in the Sudetic Foreland, southwestern Poland. *Geologia Sudetica*, **31** (2), 171-196.

RIEZEBOS, P.A. 1979. Compositional downstream variation of opaque and translucent heavy residues in some modern Rio Magdalena sands (Colombia). *Sedimentary Geology*, **24**, 197-225.

SAWICKI, L. 1972. Objaśnienia do Szczegółowa mapy geologicznej Sudetów w skali 1 : 25 000, arkusz Podlesie. *Państwowy Instytut Geologiczny*; Warszawa.

SHILO, N.A. 2002. Teaching on placer deposits: the placer forming ore associations and generation theory, 2nd ed., pp. 1-576, *Dalnauka Publication*; Vladivostok. [*In Russian*]

SPECZIK, S. & WIERCHOWIEC, J. 1991. Evolution of placer gold occurences in the vicinity of Lwówek Śląski, SW of Poland. *In*: M. PAGEL & J.L. LEROY (*Ed*s), Source, transport and deposition of metals, pp. 709-713. Rotterdam.

SPECZIK, S. & WOŁKOWICZ, W. 1995. Orogin of alluvial gold – a case study of Bóbr river deposits. *In*: J. PASAVA, B. KRIBEK & K. ZAK (*Eds*), Mineral deposits: from their origin to their environmental impacts, pp. 195-198, *Balkema Publishers*; Rotterdam.

STANAWAY, K.J. 1992. Heavy mineral placers. *Mining Engineeing*, **4**, 352-358.

VEČEŘA, J. 1996. Mekke doly ve Zlatých Horách. *Sborník Montanisticko-Geologické Nadace*, **2**, 53-57.

VOGEL, K.R., SLINGERLAND, R.L. & BRIDGE, J.S. 1992. Routing of heterogeneous sediments over a movable bed: model verification. *Journal of Hydraulic Engineering*, **118**, 263-279.

WIERCHOWIEC, J. 2001. Origin of placer gold occurrences in the vicinity of Głuchołazy, SW Poland. *In*: A. PIESTRZYŃSKI (*Eds*). Mineral deposits at the Beginning of the 21st century, 835-838, *Balkema Publishers*; Lisse.

— 2002a. Morphology and chemistry of placer gold grains – indicators of the origin of the placers: an example from the East Sudetic Foreland, Poland. *Acta Geologica Polonica*, **52** (4), 563-576.

— 2002b. Złotonośność trzeciorzędowych i czwartorzędowych osadów rzecznych na przedpolu Sudetów Wschodnich. *Przegląd Geologiczny*, **50**, 818-819.

— 2006. Preglacial to Holocene auriferous sediments from the East Sudetic Foreland, Poland: gold grade and exploration. *Geological Quarterly*, **50** (2), 289-302.

WIERCHOWIEC, J. & WOJCIECHOWSKI, A. 1997. Perspektywy występowania złota w osadach okruchowych trzeciorzędu i czwartorzędu rejonu Otmuchów–Głuchołazy–Prudnik. *In*: A. MUSZER (*Eds*), Metale szlachetne w NE części Masywu Czeskiego i w obszarach przyległych. Geneza, występowanie, perspektywy, pp. 99-104, Wrocław.

WILSON, A.F. 1984. Origin of quartz-free gold nuggets and supergene gold found in laterites and soils. A review and some new observations. *Australian Journal of Earth Sciences*, **31**, 303-316.

— 1993. Okruchowe złoża złota w dorzeczu środkowego Bobru. *Posiedzenia Naukowe Państwowego Instytutu Geologicznego*, **49** (1), 13-14.

— 1994. Okruchowe złoża złota na północnym przedpolu Gór Kaczawskich – stan obecny i perspektywy. *Posiedzenia Naukowe Państwowego Instytutu Geologicznego*, **50**(2),16-18.

WOJCIECHOWSKI, A. 1997. Przejawy złota pierwotnego w amfibolitach okolic Burgrabic k/Głuchołazów. *In*: A. MUSZER (*Eds*), Metale szlachetne w NE części Masywu Czeskiego i w obszarach przyległych. Geneza, występowanie, perspektywy, pp. 68-69, Wrocław.

WROŃSKI, J. 1975. Procesy endogeniczne na obszarze wschodniej części bloku przed- sudeckiego. *In*: J. LISZKOWIAK & J. STOCHLAK (*Ed*s), Recent and neotectonic crustal movements in Poland, pp. 171-183. Warszawa.

YOUNGSON, J. & CRAW, D. 1993. Gold nugget growth during tectonically induced sedimentary recycling, Otago, New Zealand. *Sedimentary Geology*, **84**, 71-88.

— & — 1995. Evolution of placer gold deposits during regional upift, Central Otago, New Zealand. *Economic Geology*, **90**, 731-745.

— & — 1999. Variation in placer style, gold morphology, and gold particle behavior down gravel bad-load rivers: an example from the Shotover/Arrow-Kawarau-Clutha river system, Otago, New Zealand. *Economic Geology*, **94**, 615-634.

ZEUNER, F. 1928. Diluvialstratigraphie und Diluvialtektonik im Gebiet der Glatzer Neisse, 1-72 *Universitätsverlag von Robert Noske*; Borna – Leipzig.

Manuscript submitted: 14th January 2007
Revised version accepted: 15th May 2007

PLATE 1

Polarized light photomicrographs of typical heavy minerals from the gold-bearing sediments. Scale as shown

1 – Hematite intergrowths (white) occurring as thin to thick lamellae, orientated parallel to the {111} planes of magnetite (light grey).
2 – Magnetite-ilmenite intergrowths represented by relatively thick, banded lamellae of ilmenite (grey) exsolved in magnetite (white).
3 – Irregular 'nucleus-like' inclusions of pyrite (light) in magnetite (dark).
4 – Very thin lamellae of hematite (white) exsolved along {111} planes of host magnetite (light grey) forming net-like haloes; homogeneous, sub-rounded magnetite grain (m).
5 – Banded hematite (light)-ilmenite (dark) exsolution intergrowths.
6 – typical hematite-ilmenite intergrowths represented by relatively thick, as well as very fine lamellae of ilmenite (grey) exsolved in hematite (white).
7 – Fragments of moderately rounded zircon crystals with inclusions.
8 – Long prismatic zircon crystal with bipyramidal terminations. Note opaque and rutile inclusions.

m – magnetite, h – hematite, il – ilmenite, py – pyrite, zr – zircon

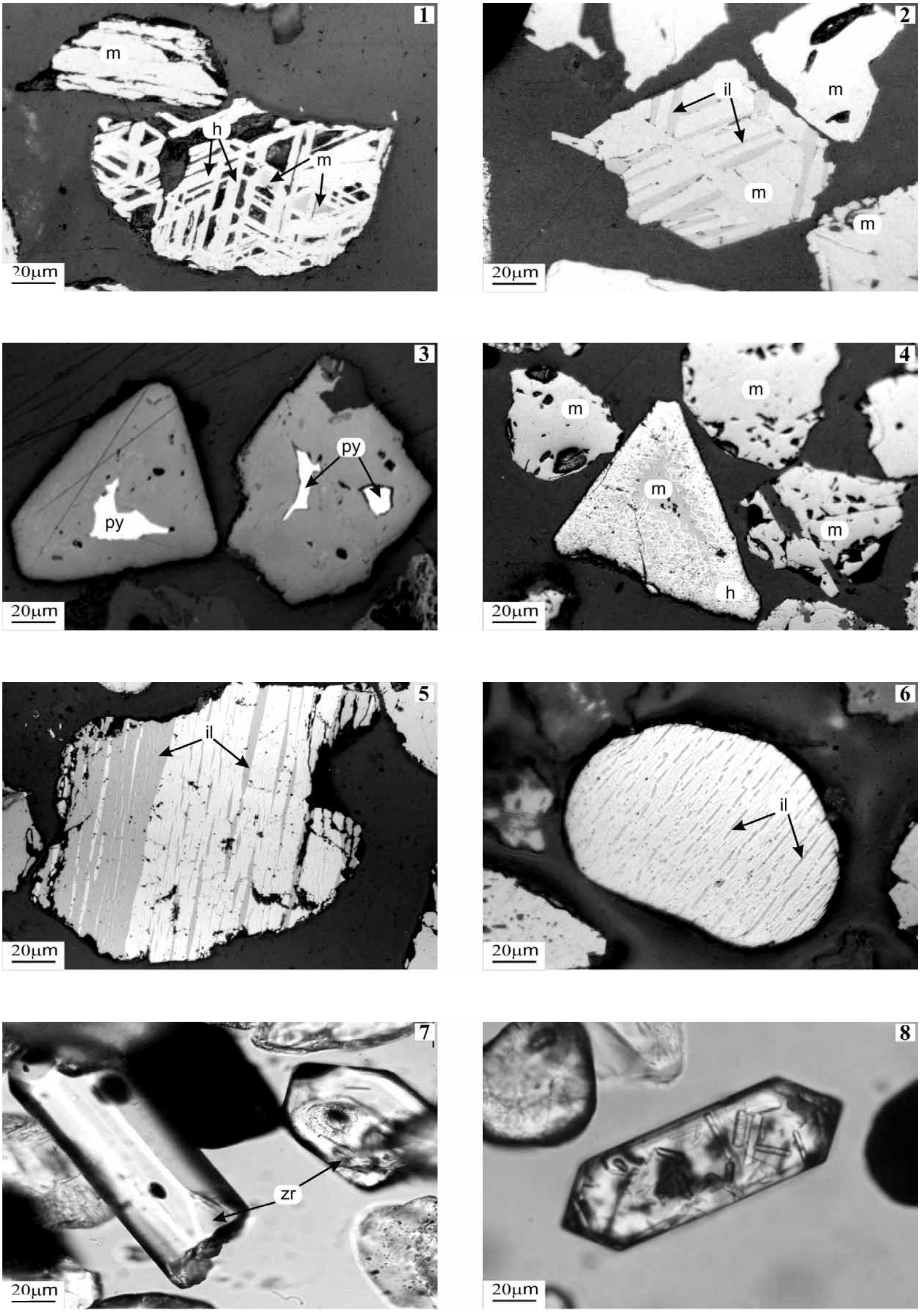

1
m
h
m
20μm
2
il
m
m
m
20μm
3
py
py
20μm
4
m
m
m
m
h
20μm
5
il
20μm
6
il
20μm
7
zr
20μm
8
20μm

PLATE 2

Secondary electron micrographs of a detrital placer gold from studied occurrences. Scale as shown

1 – Rough surfaced, knobby-shaped grain with cavities on the grain surface. Note highly porous worm-like concentrations of secondary gold and freshly deposited clay minerals (light) filling some cavities (Pgp).

2 – Moderately flattened grain showing evidence of abrasion and rounding (a); 'sandwich-like' particle with marks of intense deformation (b) (Pgp).

3 – Typical platy gold particle from sheetflood fine gravels; note microhammer marks, scratches, pits and quartz detritus on the grain surface (Pgd).

4 – Reflattened, 'sandwich-like' particles with marks of intense deformation (Pgd).

5 – Rod-like particle; note straight particle edges (fold hinges) (Qh)

6 – Platy, reflattened particle with pits and quartz detritus on the surface; sample from the southern part of the Paprotnik valley (Qh).

7, 8 – Surface microtexture of gold particle generated by smearing irregular cavities with trapped angular quartz detritus.

Pgp – proximal palaeofan deposits, Pgd – distal palaeofan deposits, Qh – recent stream sediments of Paprotnik river

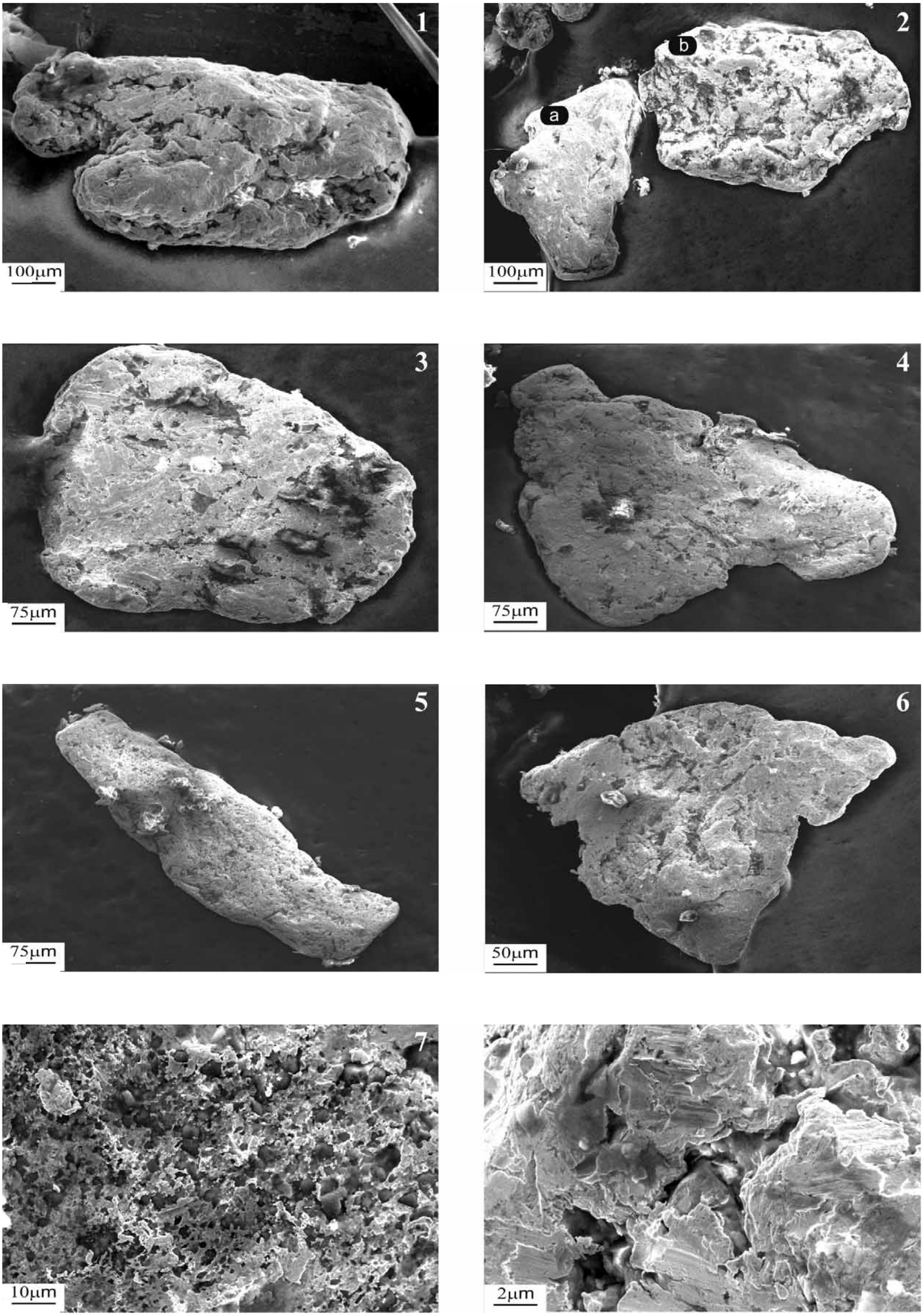

1
100µm
2
a
b
100µm
3
75µm
4
75µm
5
75µm
6
50µm
7
10µm
8
2µm

PLATE 3

Back-scattered electron images of placer gold grains showing texture and intra-grain chemical heterogeneity on sectioned (polished) particles. The lighter the tone the higher silver content. Scale as shown

1, 2 – Primary grain core (dark gray) surrounded by the Ag-poor rim (light gray). Note the deformation of both the rim and the core (Pgd).

3 – Particle with irregular grain-boundary geometry. Figure illustrate how smearing of the rim can form a cavity (Pgp).

4 – The middle Ag-rich zone surrounded by a nonporous (massive), high purity Au rim (light gray). The numerous black spots in the rim are the polishing compound (diamonds). Note the sharp core-rim contact (Pgp).

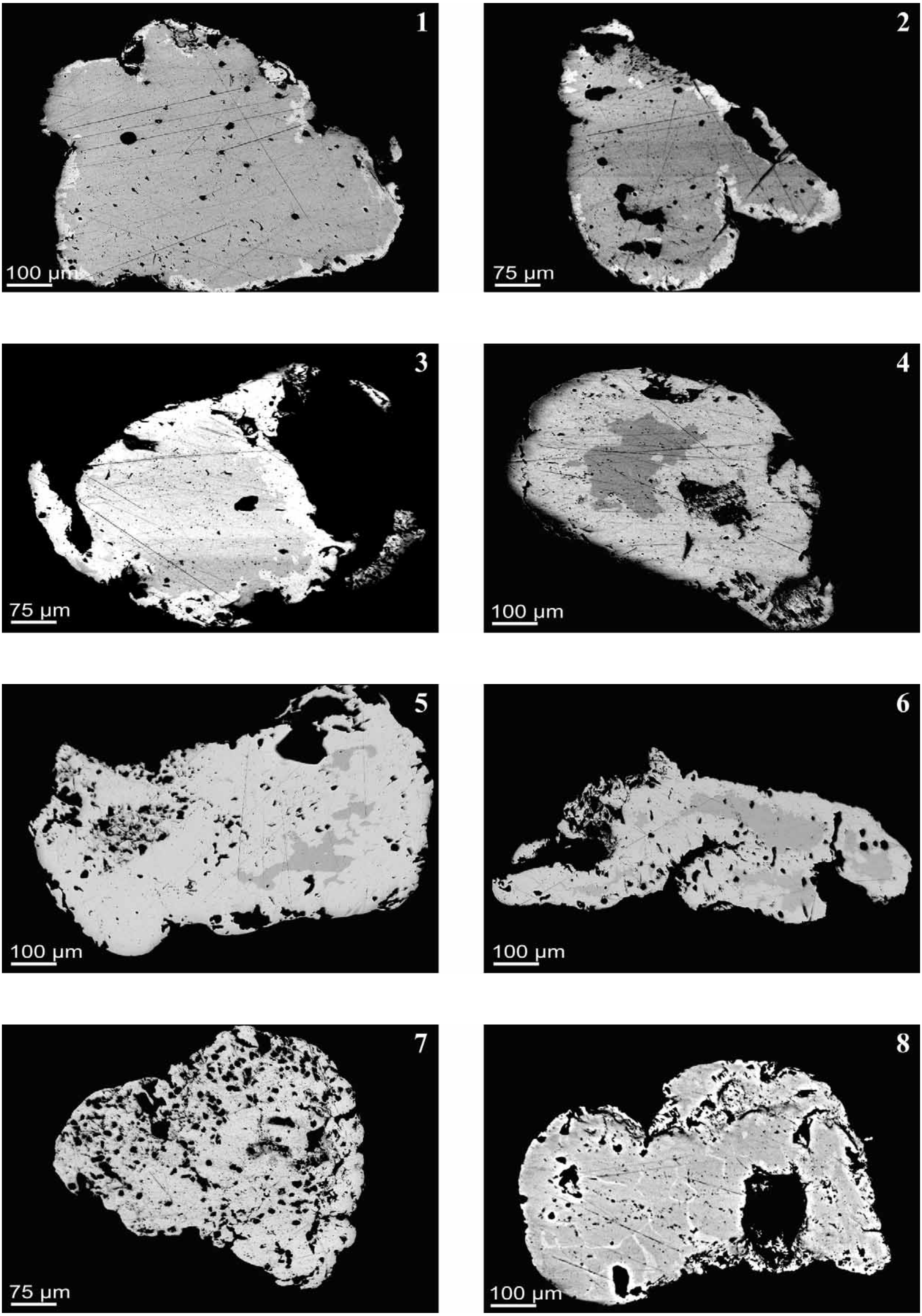
5 – Irregular particle with ragged multiple cores. The dark gray areas are the remnants of original core of the particle (Qh).

6 – Multiple cores in a porous placer gold particle. Note high Ag, the pore-free cores surrounded by pores, pure gold rim (Qh).

7 – Compositionally homogeneous, knobby-shaped high purity Au particle. Show complex grain-boundary geometry and the characteristic sponge-like internal structure (Pgp).

8 – Inhomogeneities in irregular gold grain. High purity Au veins within a Ag-rich particle Note the well defined, sharp veins contacts and zones of pure gold on grain margin (Pgp).

Pgp – proximal palaeofan deposits, Pgd – distal palaeofan deposits, Qh – recent stream sediments of Paprotnik river


1
100 µm
2
75 µm
3
75 µm
4
100 µm
5
100 µm
6
100 µm
7
75 µm
8
100 µm