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The perspective and prognostic areas of zinc and lead ores in the Upper Silesia Zn-Pb Ore District

Introduction

This article is an expanded and updated version of the article (Mikulski et al. 2011), which in summary form was published in Wołkowicz et al., eds. (2011). The criteria determining the perspective and prognostic resources were adopted according to Smakowski, Szamałek (2011). They defined that: "Deposits/perspective areas designed by the indications of the possible presence of deposits, such as geochemical and geophysical anomalies or petrographic or mineralogical indicators of occurrence of raw minerals". The size of deposit is unknown. Prognostic deposits are determined on the basis of the few, rare workings or natural outcrops and geophysical data which allow to determine approximately the area of possible deposits and the nature and quality of the ore. For determination of Zn-Pb deposit boundaries as suitable for possible mining there are defined criteria listed in Table 1.

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TABLE 1

Criteria of Zn-Pb ore deposits introduced by regulation of the Minister of the Environment of 9 January 2007

TABELA 1

Kryteria bilansowości dla złóż rud Zn-Pb wprowadzone Rozporządzeniem Ministra Środowiska z dnia 9 stycznia 2007 r.

Criteria	Parameters for sulfide Zn-Pb ore deposits	Parameters for oxidized Zn-Pb ore deposits
Cut-off grade (combined Zn+Pb in sulfides or only Zn in oxidized ore) in the sample contouring deposit (regardless of the degree of sulfide ore oxidation)	2%	5%
Minimum weighted average of combined Zn+Pb content (sulfide ores) or only Zn (oxidized Zn-Pb ores) in the profile of the deposit together with barren intercalation	2%	5%
Accumulation index in ore zone	5 m%	10 m%
The maximum depth to deposit bottom surface	500 m	500 m

1. The present state of Zn and Pb resources reported in Poland

In the Upper Silesia Ore District occur explored Zn-Pb deposits that were subject of long mining exploitation. These deposits are traditionally classified as deposits of Mississippi Valley Type – MVT (e.g. Sass-Gustkiewicz et al. 1982). The main deposits of economic value are hosted by the Ore-bearing Dolomite of the Muschelkalk (Middle Triassic), (Górecka 1993). It was estimated that from this lithological unit comes ca. 95% of total metals production (Szuwarzyński 1996) and the rest from Roethian and Devonian strata. Zn-Pb ore bodies mined from this region are mainly stratabound or nest-like karst breccias and occur from 40 to 240 m below surface (Blajda et al. 1997). The average content of metals in sulfide ores is usually ranging from 2 to 4% Zn and 1 to 2% Pb. The initial total ore resources are estimated for ca. 0.7 billion t of Zn+Pb ores at 4 to 6% and considered as the richest known Zn-Pb deposits of the MVT in the World (Cox, Singer 1986; Leach et al. 2003). The MVT deposits located at the area about 1000 km^2 are grouped in the five regions: Olkusz, Chrzanów, Bytom, Zawiercie and Tarnowskie Góry (Fig. 1).

At present exploitation is carried out only in the Olkusz region from Olkusz sublevel, Pomorzany and Klucze I deposits (Smakowski et al. eds., 2011).

The current demonstrated resources of zinc and lead ores in Poland are 79.01 million t of sulfide ores containing 3.52 million t of Zn and 1.485 million t of Pb (Table 2). In the exploited deposits occur 25% of total sulfide ores and the rest in abandoned and undeveloped deposits (Blajda 2010a, b).

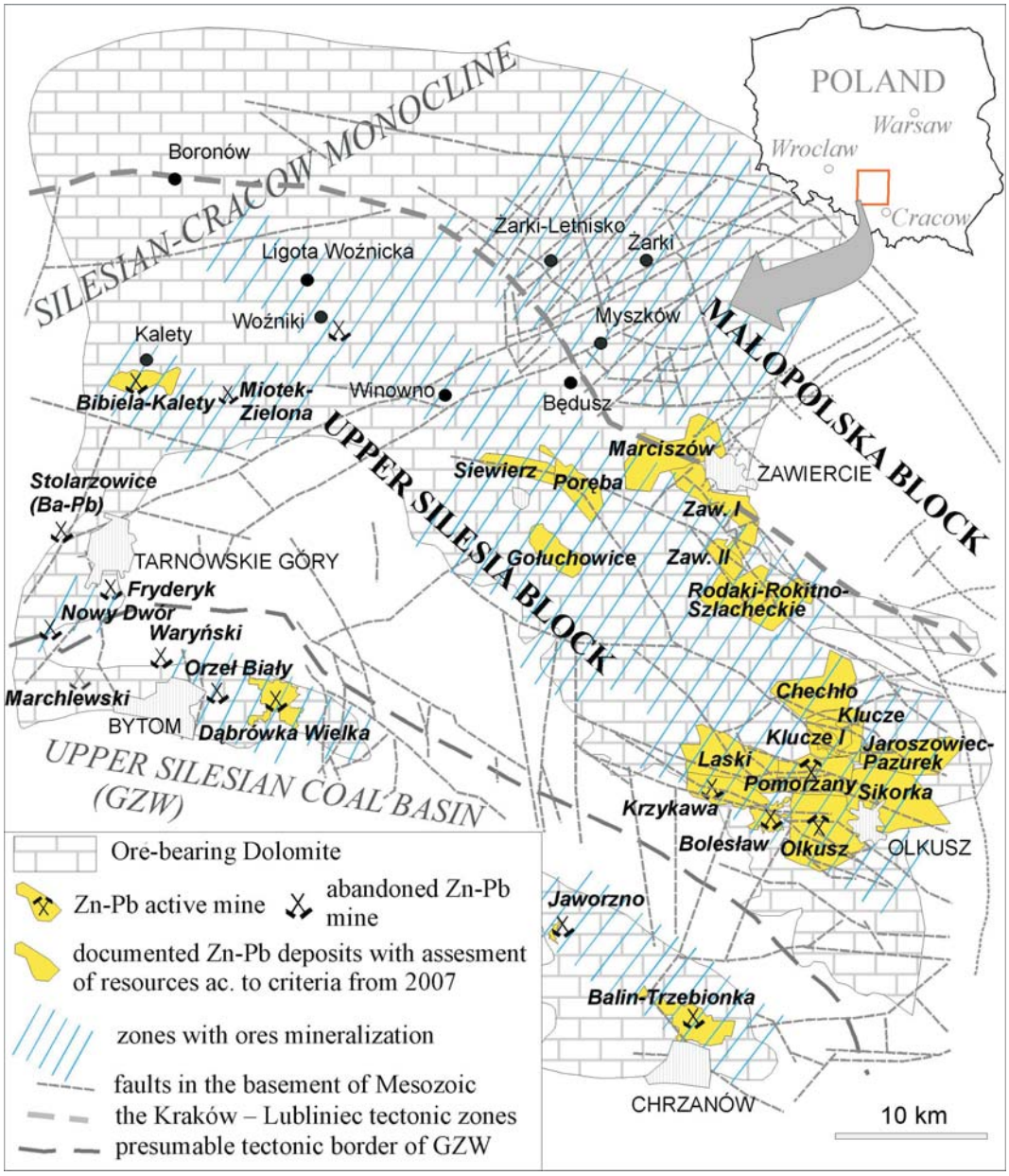

Fig. 1. The location of documented Zn-Pb sulfide deposits and oxidized Zn deposits (galman; undivided) in the Silesian-Cracow region (after Mikulski et al. 2011)

Rys. 1. Lokalizacja udokumentowanych złóż siarczkowych Zn-Pb i rud tlenowych Zn (galmany; nierozdzielone) w regionie śląsko-krakowskim (wg Mikulski i in. 2011)

TABLE 2

Zinc-lead ore resources reported in Poland at the end of 2011 (Szuflicki et al. 2012)

TABELA 2

Udokumentowane zasoby rud cynkowo-ołowiowych w Polsce na koniec 2011 r. (Szuflicki i in. 2012)

Regions with documented Zn-Pb deposits	Number of deposits (under exploitation)	Ore resources		
		Ores [million t]	Metallic Pb [thousand t]	Metallic Zn [thousand t]
Olkusz	10 (3)	37.695	797	1 589
Zawiercie	7 (–)	41.315	688	1 932
Chrzanów	1 (–)	uneconomic	–	–
Bytom	2 (–)	uneconomic	–	–
Total	20 (3)	79.010	1 485	3 522

2. The perspectives for exploration for new Zn-Pb deposits in the Upper Silesia District

In Poland the most perspective areas of Zn-Pb ores occurrences is still considered the Upper Silesia District, where it is possible to expect a stratabound Zn-Pb deposits of Mississippi Valley Type (MVT). Moreover, also the oxidized Zn ores, named galman in polish mining terminology, occur in weathered zones of primary sulfide Zn-Pb ores. Prospective formations for the occurrence of Zn-Pb deposits are carbonaceous sediments of the Middle and Lower Triassic developed mainly as the Ore-bearing Dolomite, carbonaceous rocks of Devonian and probably the Lower Triassic sediments of Bunter represented by quartz sandstones (Bolewski, Gruszczyk eds., 1986). The most important for the Zn-Pb deposits occurrence following factors are recognized: the presence of the Ore-bearing Dolomite, horst-graben structure of Paleozoic basement and Permian-Mesozoic cover, transition zone from limestone to replacement at Ore-bearing Dolomite (Ekiert 1961; Gruszczyk, Paulo 1976), porosity as well as chemical and lithologic variability of dolomites (Smakowski, Wielgomas 1986; Przeniosło, Wołkowicz 1993). During ore prospecting additional indicators are also hydro-, and litho-geochemical anomalies as well as the geo-electric anomalies (IP – inductive polarization; Retman, Wierchowiec 2008).

2.1. The Olkusz region

Recently, the Olkusz region is the most important mining area of Zn-Pb ores in Poland. There are located 3 exploited deposits – Pomorzany, Olkusz sublevel and Klucze I with an

annual production 2.345 million t Zn-Pb ores containing 82 thousand tons of Zn and 28 thousand tons of Pb (Szuflicki et al. eds., 2012). In this region 10 deposits have already been documented, however the exploitation in the Bolesław and Krzykawa deposits was terminated. The next 5 deposits in this area (Fig. 1): Klucze, Chechło, Laski, Sikorka and Jaroszowiec-Pazurek are small in size and undeveloped. The reserves of the Pomorzany deposit (A + B + C1 categories) of the average thickness 4.4 m were recognized at depth within an interval from 142 to 64 m below surface. In the central part of the deposit dominate breccias type of ores characterized with a thickness >30 m and Zn/Pb ratios reaching 4/1. In the margin part of the deposit prevailing metasomatic type of ores in form of nests up to 5.5 m thick (Zn/Pb = 2/1) (Retman 2006). The limited increase of Zn-Pb resources, about 1.0 million t ores of low quality – 3.0% Zn and 1% Pb) is mostly expected every year in the northern part of the deposit (Wnuk, Retman 2007) and development at least of part of low grade resources (ca. 1.5 million t ores – 2.4% Zn and 0.4% Pb). Moreover, the results of geophysical prospecting by IP method on the area surrounding the Pomorzany deposit indicated for increase of Zn-Pb resources for ca. 4.0 million t of a nest-like sulfide ores containing 3.3% Zn and 1.3% Pb (Retman et al. 2008).

The prospecting drilling carried out from 2009 by the ZGH Bolesław S.A. in the concession block, on the margins of the Pomorzany deposit, allowed to specify the new perspective areas for underground exploitation scheduled to start after 2013, when previous mining concession terminate.

The Klucze deposit is located ca. 2 km northwards from the Pomorzany deposit. The characteristic shape of ore bodies in the Klucze deposit area, are nests and chimneys, containing mineralized breccias and mega-breccias. The „Rudnica Nest" and „Western Nest" which are a part of the Klucze deposit are the most important. These vertical ore bodies characterized with an average high equal of 19.9 m, and a maximum ca. 60 m were formed as result of karst-collapsed processes in carbonaceous sediments of variable age. Sulfide ore mineralization occur at the interval from 50 to 472 m below surface (including collapse structures down to 385 m). Ore resources (C_1-C_2 categories), in total are estimated for ca. 3.5 million t of Zn-Pb ores (Kurek, Kmieciak 2006a). This resources are classified as the prognostic resources. Detailed data on Zn and Pb sulfide occurrences in boreholes indicate that in the area of the "Rudnica Nest" exist possibility for increase of prognostic ore resources up to 3–4 million t of low quality ores and additionally about 4.5 million t of Zn-Pb ores in collapse structures of "Rudnica" and "Western" nests (Walczak, Wnuk 2007a).

The Klucze I deposit constitute the marginal, southern part of the Klucze deposit in the Pomorzany trough. Partially oxidized sulfide ores occur mainly within the Ore-bearing Dolomite of the Middle Triassic (from 119 to 95 m below surface) in irregular nests (breccias, metasomatic ores) of average thickness ca. 3.1 m. The calculated resources (ac. to criteria from 2001) for the Klucze I deposit were estimated at only 54 metric tons of Zn-Pb ores (3.3% Zn/0.2% Pb; Kurek, Kmieciak 2006b). However, as result of detailed chemical analyses of sulfide mineralization in boreholes has been shown possibility of

increase of resources at least for 1.0 million t (3.0% Zn and 0.8% Pb (Wnuk, Retman 2007). Geophysical investigation by IP method carried out on the surrounding field of the deposit showed additional possibility for the increase of nest-type ore resources for ca. 1.2 million t at 3.3% Zn and 1.2% Pb (Retman, Wierchowiec 2008).

The Bolesław and Krzykawa deposits are recently not exploited, but still have Zn-Pb ore resources which were not extracted due to technical reasons. In the Bolesław deposit at depth above 260 m above the sea level remains still ca. 1.7 million t ores (A + B categories) containing 3.5% Zn and 0.8% Pb, and in the Krzykawa deposit ca. 2.2 million t ores (A + B + C_1 categories) containing 3.8% Zn and 0.5% Pb (Wnuk, Retman 2007).

The Sikorka deposit is located close to Pomorzany mine and south of the Jaroszowiec--Pazurek deposit. In the southern part were documented ore bodies which are grouped in the zone along the NW-SE direction (Kurek, Kmieciak 2007c). In the rest part of the area separate small ore bodies without an economic value and Zn-Pb sulfide occurrences are known. There are the possibility to increase of the resources at least for a few millions t of Zn-Pb ores but more details prospecting is necessary by induced polarization (Nieć et al. 2008).

The Chechło deposit is located in the northern part of the Olkusz region, close to the Klucze deposit, to which is very similar. Almost half of the total Zn-Pb ore resources is located in Devonian carbonaceous rocks (Kurek, Kmieciak 2007d; Wnuk 2007). However, the Chechło deposit should also be subject of more details prospecting by geophysics (IP method) and drillings for preparation its better geological model (Nieć et al. 2008).

In the period from 2003 to 2008 the ZGH Bolesław S.A. exploited 2.0 million t of ores containing 3.3% Zn and 0.9% Pb, however decrease of resources was compensate by its gain as results of more detailed prospecting for 1.1 million ton (3.4% Zn and 1.1% Pb).

The Laski deposit has been considered as the direct extension of ore resource base for the Olkusz-Pomorzany mine. Detailed review of the sulfides occurrences in borehole cores, described in the geological documentation, and not satisfying the criteria of 2007, revealed the possibility of a significant increase in perspective resources estimated at ca. 12 million tons of sulfide ores containing 2.6% Zn, and 0.3% Pb (Walczak, Wnuk 2007b; Kurek et al. 2006). Therefore, an additional geophysical prospecting (IP) should correctly predict the places where there is a chance to detect the additional resources important for the Pomorzany mine.

The estimated prognostic resources in the Olkusz region are presented in Table 3. Total ca. 45.8 to 51.8 million t Zn-Pb ores in the area ca. 300 km^2 were predicted. Part of these deposits of that region (Chechło, Klucze, Klucze I, Jaroszowiec-Pazurek and NE part of the Pomorzany mine and the northern part of the Sikorka deposit) are located within the boundaries of the Jurassic Landscape Park. Such their location may restrict the possibility of Zn-Pb ore prospecting by drilling and future mining.

TABLE 3

The prognostic resources of Zn-Pb ores in documented deposits in the Olkusz region

TABELA 3

Zasoby prognostyczne rud Zn-Pb w udokumentowanych złożach w regionie olkuskim

Deposit	Zn-Pb prognostic resources [million t]
Pomorzany	10–15
Laski	12
Klucze	7.5–8.5
Olkusz	5
Chechło	3
Sikorka	3
Krzykawa	2.2
Bolesław	1.7
Klucze I	1.2
Jaroszowiec-Pazurek	0.2
Total	45.8–51.8

After Mikulski et al. 2011

2.2. Zawiercie region

Zn-Pb deposits in this region occur between Zawiercie in the East and Siewierz to the West (Fig. 1). As a result of intensive prospecting conducted from the early 1950s to the end of the eighties of last century there have been documented the following deposits: Marciszów, Poręba, Rodaki–Rokito Szlacheckie, Siewierz, Zawiercie I (uplifted part), Zawiercie II (down faulted part) and Gołuchowice. The sulfide ores (sphalerite, wurtzite and galena; Gruszczyk, Wielgomas 1990) associated by marcassite and pyrite occur in the form of nests, pockets, and pseudo-layers mainly in the Ore-bearing Dolomite within Gogolin and Górażdże Beds. The demonstrated resources (Table 3) are also in the Devonian and Roethian carbonate rocks (Blajda et al. 2006). Locally it was found rich ore mineralization of a significant thickness but of limited extension. The proportion of Zn sulfide ore to Pb in this region is 3.3:1 (Gruszczyk, Wielgomas 1990).

The resources of these deposits were calculated to be of 41.315 million t of ores containing 1.932 million t zinc and 0.688 million t of lead (Table 2). They are approximately 52.3% of the total resources of the Upper Silesia District. The resources of poorly recognized deposits like Marciszów, Siewierz and Poręba are classified as inferred (in C_2 + D categories).

2.2.1. Zawiercie I deposit

This deposit is partly located within the area of Zawiercie city and constitute the northeastern part of the uplifted part of the Zawiercie deposit (Fig. 1) which was documented in 1967. The main ore bodies appear on the horst structure in the bottom section of the Ore-bearing Dolomite comprising the top of the Gogolin Beds and the bottom part of the Górażdże Beds (Przeniosło et al. 2008b). The deposit is developed as nests type ore bodies that deep in a south-east direction at low angle. The ore consists of fine-grained sphalerite, and in the upper parts with zinc blende (Przeniosło 1974). Currently demonstrated resources ($C_1 + C_2$ categories) are of 17.008 million tons of ores at 5.1% Zn and 2.1% Pb (Mikulski 2010). The ore bodies are located in the interval at the depth from 50 to 230 m. The two mineralized DK1 (Ore-bearing Dolomite of thickness 20 m from the bottom to the top of the bed) and DK2 (Ore-bearing Dolomite of thickness >20 m from the bottom of the bed dolomite) levels were distinguished. In the bottom part of the Ore-bearing Dolomite (DK1) were identified 13 ore bodies of surface from a few to about 50 ha, random distributed in the whole area of the deposit (Fig. 2A). In the DK2 level 12 ore bodies of small size

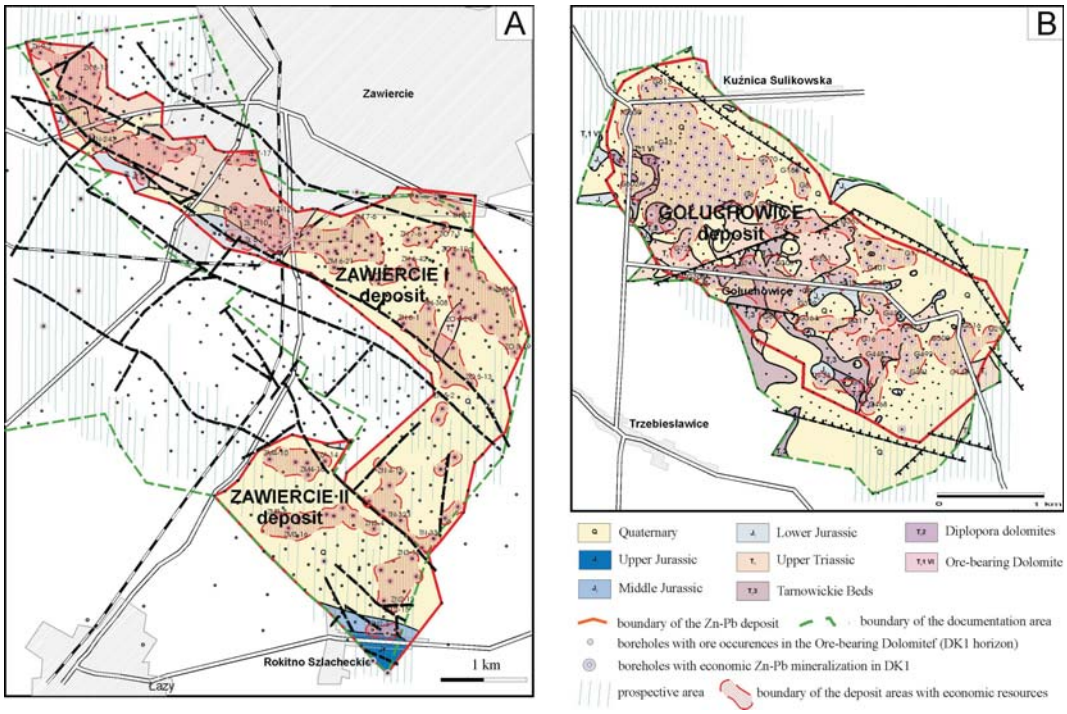

Fig. 2A–B. Map of Zn-Pb sulfide mineralization in the Ore-bearing Dolomite in the DK1 horizon in the Zawiercie I, Zawiercie II (A) and Gołuchowice deposits (B), after Mikulski et al. (2010) with Zn-Pb ore prospective areas

Rys. 2A–B. Mapa mineralizacji siarczkowej Zn-Pb w dolomitach kruszconośnych w poziomie DK1 w złożach Zawiercie I, Zawiercie II (A) oraz Gołuchowice (B), wg Mikulski i in. (2010) wraz z obszarami perspektywicznymi rud Zn-Pb

were identified. Between these areas, there are places with the prognostic and prospective resources. It was estimated that it is ca. 155 ha ore zone within the DK1 horizon, between the borders of the demonstrated resources in C_2 category, and the designated boundaries of the prognostic resources in the D category. In the DK2 horizon the prognostic resources in the D category were estimated at more than 2.1 million t of ore between already documented ores (Fig. 2A), (Mikulski et al. 2011).

The detailed analysis of the ore presented beyond the documented intervals, not satisfying the criteria from 2007, indicate the possibility of prospective resources in the amount of ca. 4.0 million tons in the interval of average thickness of 3.7 m (Socha 2007) (Table 4).

2.2.2. Zawiercie II deposit

The structure and the shape of the deposit is poorly recognized due to intense faulting, particularly in the Western part. Zn-Pb mineralization is hosted by rocks of Lower Muschelkalk, which consists of dolomitized topmost part of the Gogolin limestone Beds and the bottom sequence of Górażdże limestone Beds replaced by Ore-bearing Dolomite (DK1 + DK2). In this deposit 2.865 million tons of ore (C_1 + C_2 category) containing ca. 0.2 million tons zinc and 0.07 million tons of lead has been documented (Przeniosło et al. 2008c). The average thickness of the ore body is ca. 2.3 m (C_1 category), and the average metals contents – 6.96% Zn and 2.43% Pb. The mineralization was documented in 42 boreholes (16% of the total drilled boreholes).

In the DK1 horizon 6 ore-bearing areas in the SE part of the deposit were distinguished. The largest of them has an area of approximately 33 ha (Fig. 2A). The footwall of the deposits is at depth from +152.1 m to +176.6 m a.s.l. The other ore bodies are smaller and have surfaces from ca. 1 to 26 ha (Fig. 2A). The characteristic feature of this part of the deposit is that between ore bodies there are many boreholes with manifestations of sulfide mineralization not satisfying the deposit criteria. In the north-western parts, where the drilling grid is very rare, mineralization were found in 13 isolated boreholes. The general possibility of occurrence of perspective resources of Zn-Pb (D category) exists in the DK1 on the area above 53 ha. In the DK2 level the Zn-Pb economic mineralization were encountered in four isolated boreholes, therefore, these resources were considered as prognostic (D category). In addition, the prognostic resources of DK2 are ca. 70 thousand tons of the Zn-Pb ores (Przeniosło et al. 2008c; Table 4).

The area of Zawiercie II requires further recognition, especially in the NW part, with use of geophysical methods (IP) and further verification by shallow drilling (250 m).

2.2.3. The Gołuchowice deposit

Resources in the C_1 + C_2 categories for Gołuchowice deposit are 16.916 million tons sulfide ores containing 0.562 million t Zn and 0.149 million t of Pb (Mikulski 2010). Average content of Zn is 3.4% and of Pb 1.1%. This deposit lies in a zone of shallow appearance of

Triassic sediments (Fig. 2B). The rocks hosting sulfide ores are north-east dipping. Zn-Pb sulfide ores in form of nests and lens-like are found mainly in the upper parts of the Gogolin limestone Beds but can be traced through ore bearing dolomites up to Diplopora Dolomites. In sulfide ore dominates a fine-grained sphalerite, which impregnates dolomites. In the upper parts of the deposit zinc blende with galena and fine-grained impregnations of galena also appears.

The mineralization within the DK1 level were noticed in 136 boreholes (ca. 23% of the all). There are 159 ore intervals with resources (C_1 – 4.9 million tons of Zn-Pb ores; C_2 – 10.96 million tons of Zn-Pb ores) with an average thickness at 3.05 m and an average zinc content of 3.35% and lead of 1.1% (Mikulski 2010). The economic resources in DK2 level were documented in 42 boreholes (11%) mainly in the North-Western and central parts. There were identified 43 intervals (C_2 – 1.05 million t of Zn-Pb ore) with an average thickness of 2.4 m and the average zinc content of 3.2% and lead of 1.0%. In the DK1 horizon can extract several different surface of ore areas, spaced evenly throughout the whole deposit. In the north-western part of the deposit the biggest area of Zn-Pb sulfide ores („Główny") with the surface ca. 129.2 ha was selected. The bottom range of the deposit lies on the level of +217.3 to +265.5 m above sea level (Przeniosło et al. 2008d).

TABLE 4

The prognostic and perspective resources of Zn-Pb ores in documented deposits of the Zawiercie region

TABELA 4

Szacunkowe zasoby prognostyczne i perspektywiczne rud Zn-Pb w udokumentowanych złożach w regionie zawierciańskim

Deposit	Prognostic resources	Perspective resources
Gołuchowice	in DK1+DK2 – 7.2 million t of Zn-Pb ores in DK2 – 95 thousand t Zn and 23.8 thousand t Pb	in DK1 – 76.5 ha
Zawiercie I	in DK2* – 2.1 million t Zn-Pb ores in DK1+DK2 – 4 million t Zn-Pb ores	in DK1* – area of 155 ha
Zawiercie II	in DK2 – 70 thousand t Zn-Pb ores	in DK1 – >53 ha
Rodaki-Rokitno Szlacheckie	in D – 0.3 million t Zn-Pb ores (9.3 thousand t Zn and 1.7 thousand Mg Pb)	
Marciszów	in DK2 and DD* 46.2 thousand t Zn-Pb ores in D* – 7.7 thousand t Zn-Pb ores	
Poręba	0.8 million t Zn-Pb ores	
Siewierz	0.3 million t Zn-Pb ores	

* DK1 – Ore-bearing Dolomite of thickness 20 m from the bottom to the top of the bed; DK2 – Ore-bearing Dolomite of thickness >20 m from the bottom of the bed; DD – Diplopora Dolomites; D – Devonian carbonaceous sediments.

After Mikulski et al. 2011

Generally, economic mineralization in DK2 level coincides with mineralization in the DK1 horizon, and differences in elevations are just a dozen meters. In addition, in the DK2 and DK1 levels many examples of sulfide occurrences were found, which do not represent the current economic criteria. The Zn-Pb ore resources of these horizons can be considered as a perspective. In the DK1 horizon, the total mineralized area reach 76.5 ha. In turn, the level of the DK2 resources prognostic in D category reach ca. 95.6 tons of Zn and ca. 23.8 tons of Pb (Table 4).

The data on sulfide occurrences found in boreholes define the possibility to increase resources in the Gołuchowice deposit at least for ca. 7.2 million tons of ore (Walczak 2007). The presence of ore bodies to the NE and SW of the explored deposit is also possible, on the area of several km^2 at least, but this should be verified (Mikulski et al. 2010). The volume of ore resources located close to the surface (from several to 110 m below surface), show open cast system for the future mining.

2.2.4. The Rodaki-Rokitno Szlacheckie deposit

This deposit is located south from the Zawiercie II deposit. In the Ore-bearing Dolomite big ore zone (about 2 x 2 km) with small ore bodies of undetermined size was located in the eastern part of the deposit (Fig. 2A). The thickness of the deposit in this zone ranges from ca. 0.9 to 6.9 m, and the average content of Zn and Pb are 2.4–5.9 and 0.1–7.8%, respectively (Preidl, Kmieciak 2007). Smaller areas (approx. 100 ha) with high Zn+Pb concentration occur around rarely grid of boreholes. In this area, it should be expected a significant increase in prognostic resources. In the south-western part of the deposit relatively large zone of sulfide ores (approx. 100 ha) hosted by the Middle Devonian carbonaceous rocks, occurring at the depth from 207 to 282 m below surface was found. Thickness of the economic intervals varies from 1.9 to 10.2 m with an average content of Zn ranging from 2 up to 5.4%, and Pb up to 1.5%. Prognostic resources of Zn-Pb sulfide ores occurring in Devonian sediments are 0.3 million tons (9.3 thousand tons of Zn and 1.7 thousand tons of Pb, Table 4).

There are a number of indications on the ability to increase the Zn-Pb perspective resources. Particularly interesting is the middle part of the deposit, where ore mineralization shall be distributed within the Ore-bearing Dolomite (DK1 and DK2) along the tectonic zones of NW-SE direction (Jarrin, Nieć 1993).

2.2.5. The Marciszów deposit

The Marciszów deposit is poorly investigated, and Zn-Pb sulfide ores were found in a single boreholes random localized on a relatively large area (Przeniosło et al. 2008a). Zinc and lead ores mineralization in the form of nests, horizontal lenses and irregular aggregates occur in tectonic zones, mainly in the lowermost parts of the Ore-bearing Dolomite (DK1), and only in some boreholes in the topmost part of the Ore-bearing Dolomite (DK2). Moreover, ore mineralization occurs also in Diplopora Dolomites in the eastern part of the

area and occasionally in the Devonian rocks. The ore bodies have thickness varies from 0.3 up to 5 metres which are located at the depth of about 100 to 230 m below surface.

Current total documented resources in the deposit is ca. 0.8 million tons of ore containing 34 thousand tons Zn and 13 thousand tons Pb (Szuflicki et al. 2012). However, there is still a possibility significant increase volume of resources after performing further exploration program (Table 4). The importance of small deposits of Marciszów raises its direct neighborhood with larger ore fields of the Zawiercie I deposit (Fig. 1).

2.2.6. The Poręba and Siewierz deposits

Previous Zn-Pb ore resources of the Poręba and Siewierz deposits (9.8 and 5.2 million tons; Szuflicki et al. 2012) were later verified according to new criteria from 2007 and only ca. 0.8 million tons (C_2+D categories) in Poręba deposit, and ca. 0.3 million tons (D category) in the Siewierz deposit were documented (Kurek, Kmieciak 2007a, b). Resources of both deposits have been classified as prognostic (Table 4).

Large part of previously presented resources, detected by few reconnaissance drillings, is located beyond the Ore-bearing Dolomite and it suggests an existence of additional ore bodies in Triassic dolomites what is typical for Upper Silesia.

3. Oxidized zinc ores in the Upper Silesia Ore District

Currently oxidized zinc ore are going through its renaissance in the world. It is caused by discovery of large deposits of oxidized zinc ores in Iran (Anguran), Kazakhstan (Shaimerden) and Namibia (Scorpio), (Sangster 2003). The new technology of processing of oxidized zinc ores with leaching acids, solvent extraction (SX) and electrolysis solution (EW) were also adopted. This technology allows to receive metallic zinc or high quality zinc oxide directly from deposit in situ. It is estimated that the global metal production in the current century from non-sulfides zinc ore will rise up to 10% (Large 2001).

In Poland the oxidized ore, called “galman”, are closely associated with the oxidation zone of sulfide ores within the Upper Silesia District (Radwanek-Bąk 1985; Coppola et al. 2009). They were well known on the outcrops of the Ore-bearing Dolomite in the belt from Trzebinia–Krzeszowice–Olkusz to Siewierz, within the Tarnowskie Góry area and in the Bytom and Chrzanów Basins (Fig. 1). Most of the oxidized ores occurred directly above the sulfide ores in the zones exposed to weathering sections (horsts, zones of breccia and curstification of the original deposit). They are represented mainly by the smithsonite-bearing galman; locally-Fe-smithsonite and hydrozinkite (Żabiński 1960).

The exploitation of galman in the Bytom area dates from the 12th century. With the beginning of the 19th century the production of metallic Zn from oxidized ore in the Upper Silesia District reached 8.9 thousand tons (74% of world production). In the 50s and into the mid-60s of the 20th century, the share of Zn-Pb oxidized ores in total resources represented

approximately 33% (Przeniosło et al. 1992). Exploitation of deposits of Zn and Pb oxidized ores in the Olkusz region was ended in 1985. However, still within the fields of the abandoned mines – Bolesław (1996) and Olkusz (horst part; 2001) and in the Krzykawa deposit (1995) remain oxidized ores which are a part of potential Zn resources.

The data on zinc oxidized ores in different mines allows to estimate their geological resources (according to the criteria from 1975) on ca. 51.19 million tons, including more than 2.984 million tons of Zn and 0.416 million tons of Pb (Table 5).

In 1989, there was stopped the extraction of oxidized ore from Dąbrówka Wielka and Orzeł Biały deposits and from mining waste of oxidized ores. In 1989, the Dąbrówka Wielka mine extracted, 244.3 thousand tons of oxidized ores with an average content of 6.5% Zn. In 1990 the volume of oxidized ores dropped to about 18%, and the average content of Zn in the ores has also been decreasing to 5.9%. In 1990 the production of zinc oxidized ores has been reduced in the WTC HC Miasteczko Śląskie because of both an economic (low efficiency of the production process) and environmental reasons (Przeniosło et al. 1992). In accordance to the adopted in 1992 the new criteria of resources and reserves, the oxidized zinc ores were completely excluded from the previous inventory. This was due to the adopted criteria of ore, in which degree of oxidation ZnO/Zn should be less 35%, and, the contents of

TABLE 5

The prognostic resources of oxidized zinc ores (based on an economic criteria from 1975)

TABELA 5

Zasoby prognostyczne rud tlenowych cynku (wg kryteriów bilansowości z 1975 r.)

L.p.	Mine or deposit	Oxidized Zn ore resources [million t]	Metal resources [thousand t]		Average content [%]	
			Zn	Pb	Zn	Pb
1.	Orzeł Biały mine	5.96	342.8	51.0	5.7	0.8
2.	Dąbrówka mine	12.24	753.3	133.2	6.2	1.1
3.	Bolesław mine	19.07	1 057.5	118.4	5.6	0.6
4.	Olkusz mine	6.16	350.4	34.6	5.7	2.7
5.	Pomorzany mine	3.58	210.3	53.6	5.9	1.5
6.	Sikorka deposit	0.70	42.3	6.6	6.0	0.9
7.	Klucze deposit	1.45	89.0	9.9	6.1	0.7
8.	Krzykawa deposit	0.2	10.0	2.0	5.0	1.3
9.	Trzebionka mine	0.26	36.9	1.3	14.1	0.5
10.	Zawiercie deposit	1.57	91.5	6.0	5.8	0.4
Total		51.19	2 984.0	416.6		

Zn+Pb in the sulfide form should be over 2%. None of the above mentioned parameters could not be fulfill by the galman from the Upper Silesia region. These resources, despite of generally unfavorable relationship of the deposit thickness to the overburden should be the subject of new economic and environmental analysis for the opencast exploitation.

A separate issue is the oxidized Zn ore gathered on wastes of former mines. Prognostic resources are there ca. 9.64 million tons of oxidized ores with 447.2 thousand tons of Zn and 88.0 thousand tons of Pb (Mikulski et al. 2011; Table 6). Partially oxidized wastes after flotation processing from the ZGH Bolesław S.A. mines collected on the tailings ponds can be an additional source of Zn and Pb in the future. There is located 42 million tons of waste containing 1.1% Zn and 0.7% Pb.

TABLE 6

Prognostic resources of oxidized Zn ores in mining wastes
(ac. to economic criteria from 1975)

TABELA 6

Zasoby prognostyczne rud tlenowych cynku w zwałach kopalnianych
(wg kryteriów bilansowości z 1975r.)

L.p.	Location	Resources of oxidized Zn ores [million t]	Resources of metal [thousand t]		Average contents [%]	
			Zn	Pb	Zn	Pb
1.	Miechowice waste N/G/25	0.20	13.8	2.0	6.9	1.0
2.	Miechowice-Bytom – rest of wastes	0.18	10.6	1.4	5.9	0.8
3.	Pomorzany – waste	0.10	6.9	1.9	6.9	1.9
4.	Brzeziny – waste	3.83	196.3	31.5	4.9–7.7	0.7–1.9
5.	Piekary Śląskie – waste	0.21	8.6	0.7	3.8–5.6	0.2–1.4
6.	Bytom – Nowa Wiktoria waste	0.87	31.1	6.3	3.6	0.7
7.	Other wastes together (17)	4.25	179.9	44.2		
Total		9.64	447.2	88.0		

Most likely galman does not survive his renaissance in Poland, mainly due to low ore quality and environmental regulations and conflict with the land use planning. The deposits are located in areas highly urbanized, and local authorities are not usually interested in the development of mining in their area (Strzelska-Smakowska 2006; 2010). Despite this, for the full assessment of the economic value of Zn-Pb ore deposits it is necessary to revise the zinc oxidized ore resources in the Upper Silesia District according to the new criteria (Fig. 1).

Conclusion

In the Silesian-Cracow region the prognostic resources of Zn-Pb sulfide ores in documented deposits are estimated from ca. 60.6 to 66.6 million tons. In the region of Olkusz it amounts to approximately 45.8–51.8 million tons Zn-Pb ores, and in the Zawiercie region about 15 million tons Zn-Pb ores (Table 7). All Zn-Pb deposits are hosted by Ore-bearing Dolomite of the Middle Triassic (Muschelkalk) and by Devonian carbonate rocks. Resources of Zn oxidized ore (galman) are close to 60 million tons Zn from which ca. 51.2 million tons are located in documented Zn-Pb deposits and ca. 9.6 million tons Zn in mining wastes.

TABLE 7

The resources of Zn-Pb sulfide ores and Zn ores (galman)
in the Silesian-Cracow region (after ref. 2011)

TABELA 7

Zasoby rud Zn-Pb oraz rud Zn (galmany) w regionie śląsko-krakowskim wg stanu na 31.12.2011

Type of ore	Area	Documented economic Zn-Pb ore resources [in Million t]	Prognostic Zn-Pb ore resources [in Million t]
Sulfide Zn-Pb ores	Olkusz region	37. 695	45.80–51.80
	Zawiercie region	41. 315	14.80
Total		**79.01**	**60.60–66.60**
Oxidized Zn ores	Silesia-Cracow district	–	51.19 (in deposits)
		–	9.64 (in mining wastes)
Total		–	**60.83**
Sum		**79.01**	**121.43–127.43**

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OBSZARY PERSPEKTYWICZNE I PROGNOSTYCZNE RUD CYNKU I OŁOWIU W GÓRNOŚLĄSKIM OKRĘGU RUD ZN-PB

Słowa kluczowe

Złoża rud Zn-Pb, rudy tlenowe Zn, zasoby, obszary perspektywiczne i prognostyczne, kryteria bilansowości

Streszczenie

Największego przyrostu zasobów rud cynku i ołowiu w Polsce możemy spodziewać się w obszarze śląsko-krakowskim, gdzie w utworach węglanowych, głównie triasu środkowego oraz dewonu, występuje mineralizacja siarczkowa Zn-Pb typu Mississippi Valley Type. W regionie olkuskim szacunkowe zasoby prognostyczne wynoszą około 50 mln t rud Zn-Pb, a w regionie zawierciańskim około 15 milionów t rud Zn-Pb. W sumie zasoby prognostyczne siarczkowych rud Zn-Pb stanowią obecnie 76–84,3% zasobów bilansowych rud Zn-Pb w udokumentowanych złożach. Zasoby rud siarczkowych Zn-Pb zostały zweryfikowane według kryteriów bilansowości z 2007 r. i oszacowane metodą autokorelacji wokół otworów z mineralizacją bilansową. W strefach wystąpień udokumentowanych złóż można liczyć na znaczny przyrost zasobów rud, ponieważ dotychczasowe rozpoznanie niejednokrotnie było oparte na zbyt rzadkiej siatce wierceń. Celowe jest przeprowadzenie szczegółowych prac geofizycznych (np. metodą IP). W przypadku pozytywnych wyników należałoby dokonać rozpoznania płytkimi wierceniami.

Zasoby tlenowych rud Zn (galmanów) wynoszą w złożach około 51,19 mln t, a w zwałach kopalnianych około 9,64 mln t i są o około 30% mniejsze od zasobów udokumentowanych rud siarczkowych w tym regionie. Galmany występujące na obszarze śląsko-krakowskim z powodu niskiej jakości, zaostrzenia przepisów środowiskowych oraz konfliktowej lokalizacji w odniesieniu do gospodarki przestrzennej nie są obecnie przedmiotem eksploatacji. Zasoby rud galmanowych wymagają weryfikacji zgodnie z nowymi kryteriami bilansowości.

THE PERSPECTIVE AND PROGNOSTIC AREAS OF ZINC AND LEAD ORES IN THE UPPER SILESIA ZN-PB ORE DISTRICT

Key words

Zn-Pb ore deposits, oxidized Zn ores, resources, prospective and prognostic areas, economic criteria

Abstract

The largest perspective of zinc and lead ore resource are located in the area of Upper Silesia District, where in the Middle Triassic and Devonian carbonate rocks occurs Zn-Pb sulfide ore mineralization of the Mississippi Valley Type (MVT). Prognostic amounts of Zn-Pb ores resources estimated in the Olkusz region are close to 50 million tons, and in the Zawiercie region 15 million tons. Actually, a total of prognostic resources of sulfide Zn-Pb ores represent 76–84.3% of all economic documented deposits. Zn-Pb sulfide ores resources have been verified according to the criteria from 2007 and their quantity evaluation based on autocorrelation around the boreholes locating economic mineralisation. In the zones of documented deposits a significant increase of resources is expected, because the actual data are based on too rare drilling grid. It is appropriate to carry out further geophysical works (e.g. IP – Inductive Polarization method) and, anomalous areas should be explored by drilling.

Oxidized Zn ore resources (galman) in the deposits are 51.19 million t and in mining wastes 9.64 million t and are ca. 30% less than the Zn-Pb sulfide ore resources in documented deposits. The galmans occurring in the Upper Silesian district due to low quality, environmental laws and conflicts with the spatial economy are not currently the subject of exploitation. The galman ore resources in undeveloped deposits require verification of resources in accordance with the new economic criteria.