

ON THE ORIGIN OF STRATA-BOUND Zn-Pb ORES IN THE UPPER SILESIA, POLAND

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Abstract: In view of the renewed discussion on the origin of Upper Silesian Zn-Pb ores we give some comments on this subject. In our opinion the recurrently invoked post-Jurassic age of these deposits is at variance with geological facts which point to pre-Jurassic age. The source of metal-bearing solutions could be looked in deeper parts of the Earth's crust, presumably in Paleozoic rocks, or in older accumulations of ore deposits regenerated during Triassic reorganization of crustal plates.

Abstrakt: W nawiązaniu do wznowionej dyskusji nad pochodzeniem i wiekiem górnośląskich złóż rud Zn-Pb autorzy uzasadniają pogląd, że przypisywanie im po-jurajskiego wieku jest sprzeczne z faktami geologicznymi, które wskazują na ich przed-jurajski wiek. Źródeł roztworów metalonośnych można się dopatrywać w głębszych częściach skorupy ziemskiej prawdopodobnie w paleozoicznych skałach, bądź w starszych złożach kruszców, zregenerowanych podczas przemieszczania się kier globalnych w triasie.

Key words: MVT deposits, age of mineralization, derivation of ore fluids.

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INTRODUCTION

The strata-bound Zn-Pb sulfide ores in the Triassic of Upper Silesia belong to the category of Mississippi Valley-type deposits (abbreviated to MVT deposits). These deposits were once designated as "Upper Silesia – Mississippi Valley type deposits" (Dunham, 1950). Recently, however, they are described as "Silesia–Cracow" ores. As in our earlier publications, in this paper we return to the name "Upper Silesian ores", unless the designation "Silesia–Cracow" is quoted in excerpts from other publications.

The origin of Upper Silesian deposits is still open to discussion. Time and again contradictory ideas on this subject have been advanced, largely because some investigators ascribe negligible importance to certain geological data that are at variance with their preconceived ideas or because of insufficient understanding of geological setting of these ores. The dispute is centered on the following subjects: 1 – relationship of ores to their karst receptacles; 2 – relationship of ore bodies to tectonic features of the district; 3 – age of ore emplacement; 4 – derivation of ore fluids, their driving mechanism and routes of migration; 5 – source of base metals.

GEOLOGIC SETTING

The Triassic sequence of Upper Silesia is separated from overlying Jurassic and underlying Paleozoic rocks by major unconformities of regional extent. The sequence begins with non-marine sandstones, conglomerates and claystones (Bunter). In the ore district, the thickness of non-marine sediments varies from zero to 20 m, but to the south-east, it may amount up to 1500 m (Moryc, 1971). The non-marine sediments are followed by 300 to 400 m thick sequence of Muschelkalk limestones and early diagenetic dolostones deposited, to a considerable extent, under oxidizing and high energy conditions. These shallow-water carbonates, in turn, are covered, with a slight unconformity, by red non-marine Keuper claystones. The claystones contain, locally, pure lacustrine limestones, the so called "Woźniki limestones" (Roemer, 1870), which are interpreted in terms of hot spring deposits (Bogacz *et al.*, 1970).

In most of Upper Silesia, the Triassic overlies almost flat-lying Upper Carboniferous Coal Measures. However, along the north-eastern margin of the Upper Silesian basin, the Triassic covers with a transgressive overlap the irregular paleorelief (change of elevation up to 300 m) of folded Lower Carboniferous and Devonian carbonates (e.g. Alexandrowicz, 1971; Wyczółkowski, 1971, 1974), whose basement consists of Lower Paleozoic sedimentary, metamorphic and igneous rocks (e.g. Wieser, 1957; Ekiert, 1971;

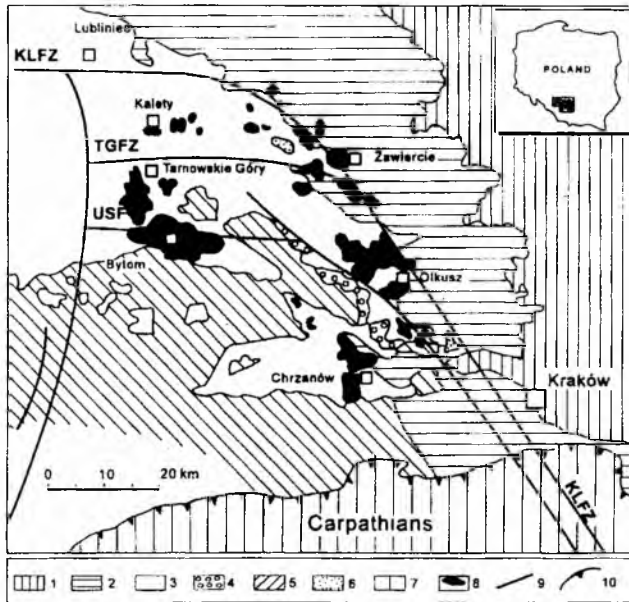


Fig. 1. Distribution of Upper Silesian Zn-Pb strata-bound ores in relation to major Paleozoic fracture zones and faults presented on a background of schematic geological map without minor tectonic features and Cainozoic strata. Paleozoic tectonics simplified after Herbich (1981) and Morawska (1997). 1 – Cretaceous; 2 – Jurassic; 3 – Triassic; 4 – Permian; 5 – Carboniferous; 6 – Devonian; 7 – Carpathians Cretaceous–Tertiary; 8 – Zn-Pb ore deposits; 9 – fracture zones and major faults; 10 – Carpathian nappes. KLFZ – the Kraków–Lubliniec Fracture Zone; TGFZ – the Tarnowskie Góry Fault Zone; USF – the Upper Silesian Fault

Ryka, 1978, Bukowy, 1994). These rocks make up the WNW–ESE trending lineament (Rulski, 1973), along the so called Kraków–Myszków structural elevation (Kotas, 1982, 1985). To the west of Myszków this elevation turns westwards and joins the W–E trending Kraków–Lubliniec Fracture Zone Fig. 1 (Morawska, 1997). This fracture zone separates the Małopolska Massif from the Upper Silesian Massif (e.g., Belka & Siewniak-Madej, 1996). It is reasonable to integrate the above mentioned fracture zones into one Kraków–Lubliniec lineament (Buła & Jachowicz, 1996; Morawska, 1997). In its present form, the Kraków–Lubliniec lineament (abbreviated to KL lineament) is a Variscan structure. It includes, however, the relics of Caledonian structures and is characterized by the presence of late Paleozoic intrusive and extrusive rocks. This lineament or fracture zone delineates the northern and north-eastern border of the Upper Silesian basin and represents a segment of the transcontinental “Hamburg–Cracow” fault zone (Oberc, 1993; Żaba, 1997). The lineament is thought to coincide with Hercynian sinistral rotation resulting from dextral strike-slip fault (Bogacz & Krokowski, 1981). It should be borne in mind, however, that the fracture zone in question extends beyond Kraków in south-eastern direction. Its prolongation has been recognized under the Carpathian nappes south of Bochnia in Rajbrot (Jachowicz & Moryc, 1995).

Starting with the Upper Paleozoic, the Kraków–Myszków structural elevation has been affected by three separate epochs of mineralization. The first, late Carboniferous–Per-

mian polymetallic vein-type mineralization, was directly related to intensive tectonics and igneous activity (e.g. Górecka, 1972; Harańczyk, 1979, 1984; Górecka & Nowakowski, 1979). The second, strata-bound mineralization, composed chiefly of sphalerite, galena and iron sulfides, is confined to Middle Triassic carbonates (Muschelkalk). The last, economically unimportant mineralization, occurs in Jurassic limestones and consists mainly of iron sulfides, galena and, locally, of insignificant amounts of sphalerite. This mineralization is genetically related to Early Tertiary faults which became truncated during the Paleogene planation. The Neogene faults which are clearly marked as horsts and grabens in the present topography of the Cracow Upland (Dżułyński, 1953) are barren of ore minerals.

Although the following discussion is chiefly concerned with ores in the Muschelkalk, the existence of early Tertiary fault-hosted mineralizations should be kept in mind, because of its bearing on the controversies concerning the origin and age of strata-bound ores in Triassic carbonates.

THE HOST ROCK OF TRIASSIC ORES

The host-rock proper of sulfide ores in the Triassic is the ore-bearing dolomite (abbreviated to OBD). This neosome or metasome occurs in the form of laterally extensive, irregular or roughly tabular bodies within unaltered Triassic carbonates (paleosome). These bodies are localized along the southwestern margin of the KL fracture zone and are absent further to the southwest, as well as on the eastern side of this structural elevation.

The cross-cutting metasomatic contacts of the OBD with unaltered Triassic carbonates and the presence of isolated remnants of these carbonates within the OBD, leave no doubts as to its secondary, metasomatic nature (e.g., Bogacz *et al.*, 1972).

The OBD resulted from successive stages, through dolomitization of limestones and recrystallization of early-diagenetic dolostones (Bogacz *et al.*, 1975). There are at least three generations of the OBD: 1 – fine-crystalline, dark dolomite with dispersed iron sulfides, 2 – coarse-crystalline rusty dolomite and, 3 – gangue dolomite in veins.

These generations (see: Krzyczkowska-Everest, 1990) were the results of the same formative process. They were directly related to the transfer of hot mineralizing solutions and mobilized connate or ground waters through the pore space of Triassic paleoaquifer.

The age of the OBD is pre-Jurassic, because the Caledonian marine sediments rest directly upon the eroded surface of this dolomite, the phenomenon already observed by early geologists (e.g. Petrascheck, 1918).

As is the case with many other MVT deposits, most students regard the OBD as a hydrothermal alteration and there is reliable evidence supporting this conclusion (for references and details, see: Bogacz *et al.*, 1972, 1975). According to some authors, however, the OBD originated independently of ore mineralization (e.g. Śliwiński, 1969).

Recently, Leach *et al.* (1996a) claim that only a limited part of this dolomite is genetically related to the emplacement of strata-bound sulfide ores. The strata-bound ores are

indeed restricted entirely and exclusively to the OBD (e.g. Michael, 1904; Sass-Gustkiewicz, 1975b, 1985; Sobczyński *et al.*, 1978). Outside the mineralized zone, the Triassic is devoid of the OBD. It should be borne in mind, however, that dolomitizing solutions were forerunning the metal-bearing ones. These latter might have covered only part of the host strata already transformed into the ore-bearing dolomite. Because of their greater specific density such mineralizing solutions emplaced ores chiefly in the lower portions of the OBD.

Admittedly, there are early diagenetic, pre-ore dolostones but they invariably occur as "stratiform" bodies i.e., normal sedimentary beds containing well preserved microfossils and other organic remnants which in the OBD are obliterated or blurred by recrystallization. The OBD is superimposed upon such dolostones and shows cross-cutting metasomatic contacts, similar to those observed with limestones.

The appearance of the OBD heralded the onset of ore mineralization and both phenomena were parts of the same formative processes. The OBD represents the first link in the chain of alterations brought about by the passage of hot ascending and mineralizing solutions (e.g. Bogacz *et al.*, 1970; Przeniosło, 1974; Mochnacka & Sass-Gustkiewicz, 1981). Therefore, the origin of OBD has been traditionally linked with the genesis of ores.

TEMPERATURE OF ORE EMPLACEMENT

The strata-bound ores in the Upper Silesia, like many other MVT deposits, are "shallow" i.e., emplaced close to the contemporary Earth's surface. Consequently, these deposits are "telethermal" and temperatures of their emplacement range from 80° to 158°C (Kozłowski, 1995) or from 120° to 220°C (Przeniosło, 1974). It is realized, however, that at greater depth, where the mineralizing fluids were derived, their temperature must have been higher (Kozłowski, 1995) and presumably inhibitory to precipitation of sulfides.

ORE-BODIES

Although the ore-bodies may assume different positions in the OBD, they are thought to occur in three so called "horizons" (e.g., Duwensee, 1928; Sobczyński & Szuwarzyński, 1974; Szuwarzyński, 1996), the lowest of which is located nearby and along the lowermost metasomatic boundary of the OBD. The ores contained in these "horizons" occur in the form of replacement (metasomatic), cavity-filling and ammoblastic ores (see later).

The problem of replacement ores has been treated in many publications (for references and details see: e.g. Bogacz *et al.*, 1973a; Mochnacka & Sass-Gustkiewicz, 1981) and does not cause controversies. Consequently, there is no need to dwell on this subject. Comments, however, are needed on the question of cavity filling ores.

CAVITY-FILLING ORES

Mineralized parts of the OBD are riddled with countless dissolution voids, which take the form of sheet-like, low-ceilinged, tabular and spongework cavities. The voids also include openings produced by "karst tectonics" (Balwierz & Dżułyński, 1976) i.e., the rock disturbances, such as collapse breccias or minor gravity faults, produced by dissolution induced stress redistribution. The above mentioned voids are lined or filled with sulfide ores.

Incipient sheet-like cavities may have formed during replacement of the OBD by sulfide minerals, when dissolution run ahead of deposition (Lindgren, 1918). Such cavities tend to occur along bedding surfaces, fractures or secondary diffusion bands (Mochnacka & Sass-Gustkiewicz, 1981; Dżułyński & Sass-Gustkiewicz, 1985; Dżułyński & Rudnicki, 1986; Sass-Gustkiewicz & Mochnacka, 1993a).

The mineralized cavities in the Upper Silesian district, as well as in other MVT deposits, are best explained in terms of hydrothermal karst phenomena as an ore-forming process (Bogacz *et al.*, 1970; Dżułyński, 1976; Dżułyński & Sass-Gustkiewicz, 1980, 1985; Sass-Gustkiewicz *et al.*, 1982; Sass-Gustkiewicz, 1985). This concept is based on three premisses: 1. the ores infilling or lining the voids are precipitated from hydrothermal solutions, 2. the voids serving as ore receptacles are of dissolution origin and, 3. the voids and ores resident in them are formed contemporaneously or penecontemporaneously by the same formative process.

The term "hydrothermal karst" is now well established in karst sciences (e.g. Kunsy, 1957; Ozoray, 1961; Maksimovich, 1969; Dżułyński 1976; Jakucs, 1977; Rudnicki, 1979; Dublyanski, 1995). Cavity making by metal-bearing hydrothermal solutions has also been suggested by several ore-geologists, either as an alternative (e.g., Park & Cannon, 1943) or explicit explanation of cavity-filling ores (e.g. Pošepny, 1894; McClelland & Whitebread, 1965). To this category of phenomena belong the cavity-filling sulfide ores in the Upper Silesian district (Bogacz *et al.*, 1970; Sass-Gustkiewicz, 1974, 1975b). The interpretation that mineralized cavities were produced by ore bearing solutions finds its strongest support in the solution collapse breccias which are among important ore receptacles. The karstic origin of these breccias is testified by the following features:

1. The lowermost boundaries of breccias are dissolution surfaces covered with mineralized cave sediments made up of grains of disintegrated dolomite and sphalerite, insoluble residuals, clastic fragments of ores and host rock, and idiomorphic sulfide crystals (Bogacz *et al.*, 1973b; Sass-Gustkiewicz, 1975a, 1996).

2. The upper and lateral boundaries of breccias are gradational, whereby the rubble of angular dolomite blocks in the center of breccia bodies passes through crackle breccias into a network of mineralized fractures. Above the high-domal breccia bodies the mineralized fissures are commonly arranged in pressure arches (Sass-Gustkiewicz, 1974).

3. In plan view, the breccias are highly irregular (Sass-Gustkiewicz, 1975b).

4. The rock fragments making up the breccia bodies are devoid of slickensided surfaces or tectoglyphs.

The mineralized breccias were formed synchronously and/or penecontemporaneously with the emplacement of ores from an alternating succession of brecciation and mineralization episodes in which the successively younger ore minerals enveloped the clastic products of earlier brecciation and mineralization episodes (Sass-Gustkiewicz, 1975b). As seen in plan view, the breccia bodies reveal concentric and zonal arrangement, with successively younger stages of mineralization covering progressively more extended areas. Such a relationship implies that both the karst receptacles and the ores resident in them are products of the same formative processes and that their coexistence in space is not due to an accidental superposition of unrelated events. This conclusion can be extended to cover the uncollapsed mineralized karst cavities. The banded ore crustifications pass from interfragmental voids of the breccias into such cavities without interruption.

Significantly, the mineralized karst cavities seldom, if ever, occur in limestones. This behaviour may be explained by the increased permeability of coarse-crystalline OBD and by the fact that at temperatures above 40 °C, the dolomite is more soluble than limestone (Mandy, 1945, *vide* Jakucs, 1977).

The dissolution motivated origin of mineralized breccias in the Triassic strata-bound deposits is ignored, minimized or rejected by authors who insist on their true tectonic derivation (e.g., Kibitlewski, 1993; Szuwarzyński, 1983, 1993). The previously indicated characteristic features of the breccias in question, however, are incompatible with their alleged true tectonic origin.

Our interpretation is also partly questioned by American investigators. The moot point in the dispute is the presence or the alleged presence of "pre-ore" breccias in the OBD, produced by dissolution motivated collapse, independently of the transfer of mineralizing solutions. Leach *et al.* (1996a) use the term "pre-ore breccia" to describe "dissolution collapse breccias which lack diagnostic evidence of involvement of either meteoric or hydrothermal fluids and whose formation predates the emplacement of ore minerals" (l.c. p. 45). The above mentioned authors conclude that "many ore-bearing breccias in the Silesian-Cracow region are REPLACEMENT BRECCIAS (capital letters by the present authors) that are the result of superposition of ore stage dissolution and hydrothermal brecciation on a pre-ore breccia and the selective replacement of pre-ore karst breccias by sulfides" (l.c. p. 46). In matrix-supported breccias, the matrix is preferentially subjected to dissolution and replacement, but from this it does not follow that the metasomatic process is superimposed upon the pre-ore breccia unrelated to the transfer of mineralizing solutions (see below).

Leach *et al.* (1996a) suggest three possibilities for the development of mineralized breccias in the OBD: 1 – meteoric karst system developed prior to the introduction of ore-forming fluids which altered and enlarged the original, meteoric collapse breccias, 2 – the pre-ore breccias developed from an earlier hydrothermal event, which was unrelated to ore emplacement and, 3 – hydrothermal karst might have formed during the initial introduction of ore-forming fluids but prior to the deposition of sulfides (l.c. p.46). The possibilities suggested have already been discussed, in a some-

what similar way, by Dżułyński & Sass-Gustkiewicz (1985, p.400).

The above listed possibilities require the following comments:

ad 1. Indeed both, the unaltered Triassic host strata and the OBD reveal meteoric karst features belonging to the three periods of meteoric karstification: pre-Jurassic, Lower Tertiary, and Pleistocene-Recent. These meteoric karst features developed under oxidizing conditions. On the other hand, the mineralized karst features in the OBD do not show any evidence of having been developed under oxidizing conditions and no coeval karst breccias of this type have ever been observed in the host strata outside the OBD. The sheet cavities which are characteristic of hydrothermal karst ores (ribbon ores) are also absent in non-mineralized carbonates. The ribbon ores, interpreted as proto-karst features, are representatives of the first stage in development of hydrothermal karst phenomena (Sass-Gustkiewicz, 1993; Dżułyński & Sass-Gustkiewicz, 1993). The mineralized collapse breccias represent the mature stage of such development. Summing up, the mineralized breccias resulted penecontemporaneously or synchronously with deposition of ores and have never been pre-ore meteoric karst features.

In the OBD, there are Lower Tertiary sinkholes containing clastic fragments of ores derived from earlier mineralizations. Such sinkholes were produced during subaerial erosion following the retreat of the Cretaceous sea. Some of them became innudated by the Miocene transgression and partly filled with marine sediments (Panek & Szuwarzyński, 1975). If this is the case, the sinkholes may contain remobilized galena crystals in shells of Miocene molluscs attached to the walls of sinkholes (Bogacz *et al.*, 1973b).

ad. 2 There is no evidence that mineralized karst cavities in the OBD developed from an earlier hydrothermal fluid event, unrelated to the ores in them.

ad. 3 The third possibility is not at variance with the concept of hydrothermal ore-forming karst processes. The formation of voids preceded shortly the emplacement of ores, but both processes were penecontemporaneous and parts of the same formative event.

Brief comments are needed on breccias which appear to be only partly mineralized. Such breccias may give the impression that mineralizing solutions invaded the pre-ore meteoric karst structures. Mineralizing solutions, however, may deposit sulfides in more permeable parts of breccias, leaving other parts of the breccias apparently barren of ore minerals. Nevertheless, such seemingly barren portions invariably contain small amounts of dispersed sulfides.

Large collapse breccia bodies in the Upper Silesian region are preferentially located along the lowermost metasomatic boundary of the OBD. This boundary approximates the top limit of the Gogolin beds which consist of fine-crystalline, thin- to medium-bedded limestones intercalated with marls. The Gogolin beds provided an impermeable floor for horizontally spreading dolomitizing solutions. The following, heavy and aggressive mineralizing solutions also moved along such an interface, taking advantage of an increased porosity of the coarse-crystalline OBD.

Converging in more passable conduits, these solutions could dissolve sizable caverns which were subject to roof

failures in bedded and cracked dolomites. Inasmuch as the roof failures propagated upwards, involving successively the overlying dolomitic beds, the rock fragments making up the breccia body consist exclusively of the OBD.

BRECCIAS NOT RELATED TO ROOF FAILURES OF CAVERNS

Not all of mineralized breccias in the OBD may be attributed to roof failures of caverns. With hydrothermal karst phenomena, new brecciating factors come into action such as "hydraulic fracturing" and "hydraulic explosions" (Muffler *et al.*, 1971; Phillips, 1972). The hydrothermal explosions result from rapid transformation of water into steam and may disrupt the confining rock. Also a sudden drop in pressure may burst it apart with the onset of dilatancy (e.g. Bridgeman, 1952; Kents, 1964). The above mentioned processes have played a dominant role in the formation of brecciated, vertical ore veins which served as channelways for ascending ore fluids (Dżułyński, 1976; Dżułyński & Sass-Gustkiewicz 1978; 1985). They also might have operated as contributory agent in brecciation of the host dolomite. The present writers, however, do not consider the hydrotectonics as the key factor in the formation of large breccia bodies in the OBD, as suggested by Jaroszewski (1993).

Brecciation is also promoted by the disrupting action of minerals crystallizing in fractures (e.g. "breche d'eclatement" – Gignoux & Avnimelech, 1937 or "chemical brecciation" – Sawkins, 1969). This process is particularly common in the OBD which is partly affected by solutional disaggregation. The solutional disaggregation may be part of hydrothermal karst phenomena. It is effected by dissolution of crystal edges, whereby the solid rock is delithified and transformed into a soft, structureless mass of incoherent or semi-coherent grains in which all traces of primary structures are obliterated.

The disaggregated grains and clayey residuals which tend to accumulate at the bottom of caverns may be redeposited by the flow of mineralizing solutions (Bogacz *et al.*, 1973b). Massive or piecemeal roof failures also stir the unconsolidated bottom materials giving rise to clouds of suspensions which may spread laterally in the form of subterranean turbidity currents (Dżułyński & Sass-Gustkiewicz, 1980).

Disaggregated dolomites, referred to as "sanded" (Lowering *et al.*, 1949) or "pulverulent" (Jakucs, 1977) provide favorable conditions for an unhindered growth of sulfide minerals. Such minerals tend to line the boundaries of disaggregated carbonates in the form of drusy incrustations projecting with their free crystal faces into the disaggregated mass of grains. This type of ore mineralization, first described from the Upper Silesian ores (Bogacz *et al.*, 1973b), has been indicated as "ammoblastesis" (Dżułyński & Sass-Gustkiewicz, 1985).

Solutional disaggregation may proceed concurrently with the ammoblastesis and may continue after the emplacement of ore minerals. In such situations, the sulfide incrustations become suspended in a mass of incoherent grains and, devoid of solid support may break into still smaller frag-

ments. Also the preexisting bedding-controlled ore veins are affected by such brecciation. With progressing disaggregation they become fragmented and displaced, though some of them are still aligned in strings, marking the original positions of veins (Dżułyński & Sass-Gustkiewicz, 1978 – Fig. 2, 1985 – Fig. 26).

Fragments of dolomite detached from side-walls of collapse breccias or cavities, which are entirely enclosed in soft matrix of incoherent grains, are subject to specific type of "self-brecciation". Such fragments, weakened by incipient disaggregation, yield to weak strains and break into smaller pieces along the pre-existing cracks. These discontinuities are widened by injected disaggregated grains and disrupting growth of autigenic sulfide crystals and form a kind of "micro-crackle breccias" (Dżułyński & Sass-Gustkiewicz, 1985; Sass-Gustkiewicz *et al.*, 1982 – Fig. 23).

RELATIONSHIP OF ORE BODIES IN TRIASSIC CARBONATES TO TECTONIC FAULTS

A key tenet of many interpretations of strata-bound ores in the Triassic of Upper Silesia is that the tectonic faults which affect the host strata have played an important role in the formation and distribution of ore bodies (e.g. Gałkiewicz, 1983; Szuwarzyński, 1993; Kibitlewski & Górecka, 1988; Kibitlewski, 1993). The possibility that some of these faults have been associated with early Cimmerian movements has also been invoked (e.g. Piekarski, 1965; Szuwarzyński, 1983). The direct relationship of the strata-bound ore to pre- or syn-ore tectonics is not clearly recorded in mine workings but appears from statistical analyses of distributions of the ore bodies (Blajda, 1993; Sass-Gustkiewicz *et al.*, 1997).

The Upper Silesian region was affected by early Cimmerian movements which appear to be recorded by some sedimentary structures (Szulc, 1993). The early Cimmerian faults might have and presumably did follow the pattern of earlier tectonic fractures although their amplitude was much smaller than that of the Variscan faults (Herbich, 1981; Górecka, 1993). However, the majority of faults which transect and displace the strata-bound ore bodies in the Triassic are post-ore phenomena related to Early Tertiary and Neogene tectonics. As noted, the early Tertiary faults were associated with local regeneration and remobilization of preexisting sulfide ores and were responsible for insignificant fault-hosted mineralization of Jurassic limestones.

AGE OF STRATA-BOUND MINERALIZATION IN TRIASSIC CARBONATES

Age of the sulfide mineralization in Triassic carbonates has long been a bone of contention between proponents of "syngenetic" and "epigenetic" interpretations. In spite of prolonged discussions no consensus of opinion has been reached on this subject.

The synsedimentary non-hydrothermal interpretation, once popular (e.g., Guerich, 1903; Stappenbeck, 1928; Keil,

1956; Gruszczuk, 1967; Smolarska, 1968) is now generally abandoned. Some proponents of epigenetic interpretations suggest post-Upper Jurassic and/or Tertiary age of the strata-bound sulfide ores in Triassic carbonates, relating this mineralization to the "Alpine tectonics" in the Carpathians (e.g. Althans, 1891; Sachs, 1930; Harańczyk, 1979; Kozłowski, 1995; Górecka *et al.*, 1996;). As an argument in favor of such interpretation, they point to the mineralization in Upper Jurassic limestones located along the early Tertiary faults. This concept has been recently accepted by American investigators (Leach & Viets, 1993; Leach *et al.*, 1996a, 1996b; Church *et al.*, 1996) and supported by Symons *et al.* (1996) on the basis of paleomagnetic investigations of ore samples. It should be born in mind, however, that Lower Tertiary fault-hosted ores may be superimposed upon the strata-bound deposits, where these deposits are cut by Lower Tertiary faults. Such situation requires precise localization of samples and their presentation against the background of ore structures in the sampling site. The samples investigated, however, do not satisfy this requirement. Moreover, any genetic hypothesis explaining the origin of MVT-deposits must be in accord with all aspects of geologic setting that existed at the time the deposit were formed (Ohle, 1980). The Tertiary interpretation of the strata-bound ores discussed is difficult to reconcile with field evidence.

As noted, the strata-bound sulfide ores are pre-Jurassic because Callovian sediments rest with transgressive overlap upon the eroded surface of the OBD which was formed penecontemporaneously with the emplacement of sulfide ores. The lowermost non-marine Jurassic sediments have been reported to rest on a karstified surface of the OBD, whereby the ores themselves have already been subjected to weathering and oxidation (e.g. Petrascheck, 1918; Piekarski, 1965).

The presence of sulfides in Jurassic limestones gave rise to the concept of multi-stage mineralization extended over a long time interval from Upper Triassic to Lower Tertiary (e.g., Rózkowski *et al.*, 1979; Szuwarzyński, 1983). The early Tertiary mineralization, however, as compared with the Triassic mineralization, took place under entirely different tectonic, structural and environmental settings. This mineralization is fault-hosted impoverished (Szuwarzyński, 1983) and does not occur in the form of strata-bound bodies. The emplacement of strata-bound ores was an earlier and separate event and not a step in a long-lasting mineralization process, embracing Jurassic and Cretaceous carbonates (see later).

The concept that the strata-bound sulfide ores were emplaced in post-Upper Jurassic or post Cretaceous time raises a number of questions which, under such assumption, remain unanswerable:

1 – Why ascending hydrothermal solutions did not spread laterally through permeable, sandy Bathonian–Callovian sediments ?

2 – Why did they deposit the bulk of their base metals in the Muschelkalk and not in bedded Upper Jurassic or Cretaceous carbonates?

3 – Why, in Jurassic or Cretaceous carbonates is there nothing comparable to the OBD?

On the other hand, the pre-Jurassic age of strata-bound

deposits explains the bedding-parallel deposition of ore-bodies. The dolomitizing solutions forerunning the emplacement of sulfides, could spread laterally, taking advantage of high primary porosity, without being inhibited or deviated by faults. The following mineralizing and aggressive solutions utilized the secondary porosity of coarse crystalline texture of the dolomitic neosome. Finally, the pre-Jurassic age of mineralization is consistent with what is known of many other MVT deposits, namely the proximity of such deposits to a regional unconformity above the host strata. The MVT deposits or, at least most of them, were emplaced close to the contemporary Earth surface.

We do not know exactly when mineralizing solutions started to invade the Triassic paleoaquifer and how long the inflow of such solutions lasted. The time interval in which the passage of mineralizing solutions persisted, estimated by Repetski & Narkiewicz (1996) as of the order 1,000 to 5,000 years, is presumably too short. Estimations by Lewchuk & Symons (1996) for the MVT from 1 to 8 My appear to be more realistic.

The beginning of inflow of mineralizing solutions began after much, if not all, of the Muschelkalk succession had been deposited. It is possible that a certain amount of metal-bearing solutions might have leaked into the sea water. Perhaps, the small quantities of dispersed sulfides reported from the uppermost lagunal Triassic sediments bear evidence to this event ("diplogenetic ores" – Lowering, 1963). Indeed, submarine exhalations of ore fluids have been suggested (Ekiert, 1957; Przeniosło, 1974; Harańczyk, 1993). However, the oxidizing and high energy sedimentary environment of the Muschelkalk was not conducive to any significant accumulation of sulfide deposits on the sea floor (Siedlecki, 1955; Krajewski, 1957). Consequently, the strata-bound deposits in the Triassic are epigenetic with respect to the host strata, not because the ore fluids could not reach the bottom surface, but because most of the metals had precipitated before reaching the bottom and because of the lack of suitable receptacles on the sea floor (Dżułyński & Sass-Gustkiewicz, 1980).

The above interpretation does not debar the possibility that the inflow of ascending hydrothermal solutions continued after the retreat of the Triassic sea. The previously mentioned lacustrine Woźniki limestones (Keuper) represent hot spring deposits, as final products of hydrothermal activity that earlier resulted in dissolution of karst cavities and emplacement of ores (Bogacz *et al.*, 1970). The hot waters, which precipitated calcium carbonate, however, were depleted of base metals. Small amounts of dispersed sulfides have also been reported from both the Keuper and Raethian sediments (Assman, 1948; Ekiert, 1957, 1971; Bednarek *et al.*, 1983; Szuwarzyński, 1996). The Keuper clays, however, did not act as a diversionary barrier for mineralizing solutions because there is no concentration of ores beneath these clays.

From the foregoing considerations, it appears that the age of the strata-bound sulfide ores is late Triassic (comp. also Ekiert, 1957; Przeniosło, 1974). Such ores are "epigenetic" with respect to the enclosing Muschelkalk carbonates but are "syngenetic" on the scale of Triassic sequence as a whole. There is yet another line of support in this respect.

According to recent preliminary investigation by Banaś *et al.* (1996) on illitization of smectite, there was a distinct thermal event by the end of Triassic time which resulted in significant rise of temperature of the Triassic strata overlying the Upper Carboniferous (see later). In this connection it is to be recalled that early isotopic age determinations of ores from Upper Silesia by Borucki (1978) have led him to conclude that the range of "analytical errors", 40 and 220 My "impairs the reliability" of these determinations. However, the first age (40 My) corresponds to Paleogene and the second (220 My) to the late Triassic. This is in agreement with the two separate epochs of ore mineralization postulated by the present authors.

DERIVATION AND TRANSFER OF MINERALIZING SOLUTIONS

The origin of ore fluids which emplaced the sulfide ores in Triassic carbonates is a matter of conjecture. Hypotheses concerning their derivation are based on preconceptions rather than on direct observations, because such observations are lacking.

The mineralization "per descendum" from overlying rocks (e.g. Althans, 1891; Sachs, 1930; Assmann, 1948) is now abandoned, because these rocks are either barren or contain too little base metals to account for large strata-bound deposits. For similar reasons, it is unlikely that the metals have been derived from compaction brines resident in Triassic host strata or from reconcentration of dispersed sedimentary ore minerals by circulating ground waters (e.g. Stappenbeck, 1928). The Triassic host strata do not show any evidences of such circulation.

On one point agreement has been reached, namely, that the ores were emplaced by ascending hydrothermal solutions. This is also indicated by ore-fluid inclusions which reveal the presence of vertical thermal fluid gradient pointing to the cooling of these fluids towards the Earth's surface (Kozłowski, 1995). Presently, the discussion is centered on migration routes of ore fluids, their driving force and the source of base metals.

The mineralizing solutions have gained access to the Muschelkalk through folded and fractured Lower Paleozoic rocks of the previously mentioned Kraków-Lubliniec Fracture Zone. Evidence for this is seen in vertical or subvertical ore veins located in faults and fractures that transect these rocks. In places of intersection of such tectonic discontinuities, the ore bodies may assume chimney-, or pipe-like shapes (Kwaśniewicz, 1932). It should be noted that large accumulations of Zn-Pb ores in Triassic carbonates occur preferentially where the underlying Paleozoic rocks are strongly tectonized (Michael, 1904).

The faults and fractures mentioned are manifestations of late Variscan orogeny associated with an elevated heat flow (Belka & Siewniak-Madej, 1996). As noted, in vaning stages of this orogeny, the movement along these discontinuities might have continued, during the onset of Triassic cycle of sedimentation (Herbich, 1981), as is the case with recent post-Alpine neotectonics. Some of the faults might have been reactivated during Early Cimmerian orogeny

(Szuwarzyński, 1983).

Mineralogical composition of these fault-hosted ore veins in Paleozoic rocks may be similar to that of the strata-bound deposits (Górecka, 1973). The ore veins reveal also similar brecciation which is explained in terms of hydraulic fracturing (Dzuffyński & Sass-Gustkiewicz 1985). Such brecciation might have been associated with "seismic pumping" (Sibson *et al.*, 1975; Sibson, 1987), as is the case with recent, earthquake generated violent expulsions of hot mineralizing solutions (Lebedev, 1974).

The ore veins are particularly well developed in folded Lower Carboniferous and Devonian carbonates. These carbonate rocks stood high in pre-Triassic topography in the form of "knobs" which are considered characteristic of the MVT deposits ("ore-knob relationship" – Ohle, 1996). From such knobs, the ascending solutions could easily cross the Paleozoic/Triassic unconformity and enter directly into horizontally disposed Muschelkalk carbonates (Alexandrovich, 1971).

The formation of extensive strata-bound deposits requires a vigorous flow of large volumes of metal-bearing solutions. To satisfy this requirement such solutions must have already been made available and it is reasonable to accept the idea of deep-seated "fossil reservoirs" as a possible sources (Fyfe *et al.*, 1978). The draining of such reservoirs must have been very rapid and with the appearance of the previously mentioned active tectonic fractures the ore fluids were abruptly released (Dzuffyński & Sass-Gustkiewicz, 1985).

Derivation of ore-fluids, driving forces, the routes of their migration and the ultimate source of base metals are open to discussion. Since the strata-bound ores are pre-Jurassic (see above), both the uplift and thrust of the Carpathian nappes could not have been the driving mechanism for ore fluids, as envisioned by some investigators (e.g. Symons *et al.*, 1995; Leach *et al.*, 1996b – Fig. 37). The Carpathians as an orogenic belt did not exist in Triassic time. The development of the Carpathian geosyncline had only just began and the accumulation of thick (7–8 km) flysch sequence started by the end of the Jurassic (Tithonian) and has continued till the Middle Miocene. At that time, the sedimentary flysch basins were situated far away to the south. Therefore the formation model depicted in Fig. 37 in the publication by Leach *et al.*, (1996b), is misleading. Admittedly, to the south of the present occurrences of Central European Muschelkalk, there existed a land area which might have given rise to topography driven flow of ore fluids (comp. Pélissonier, 1965, Rózkowski *et al.*, 1979; Church & Vaughn, 1993), but evidence in this respect is inconclusive.

An alternative to the long-distance lateral flow of hydrothermal fluids, is the short-distance flow from sources located nearby beneath the present occurrences of strata-bound deposits. Wodzicki (1987) suggested a reasonable hypothesis that the ores under consideration resulted from episodic expulsion of ore fluids from Carboniferous strata during Early Cimmerian orogeny. The Coal Measures are occasionally cut by ore veins, but these veins may also be interpreted as channelways of ore fluids derived from pre-Carboniferous rocks (e.g. Kosmann, 1883; Krusch, 1929).

As is the case with many other MVT deposits, the

strata-bound ores under consideration do not reveal any direct relationship to igneous rocks. Many authors, however, suggest a magmatic origin of these ores (e.g. Krusch, 1929; Harańczyk, 1963, 1984; Pafys, 1967; Gałkiewicz, 1971; Kucharski, 1996). There is, indeed, a striking spatial coexistence between the localization of strata-bound ores in Triassic carbonates and the appearance of igneous rocks in the underlying Paleozoic strata (Belka & Siewniak-Madej, 1996). It should also be born in mind that the KL lineament (KL fracture zone) was associated with igneous intrusions which materialized in the formation of a large batholith (Rulski, 1973, Kucharski, 1996). We do not know how long it takes for a large, deep-seated batholite to lose its last manifestations of the thermal activity. Perhaps, the time interval between the last manifestations of igneous activity in the Paleozoic and the emplacement of Zn-Pb ores in the Triassic (c.a. 40 My) was not long enough to preclude a genetic relationship between these two events.

Przeniosło (1974) is ready to accept such a possibility. He suggests that the Variscan magmatism and the emplacement of strata-bound ores in the Triassic have a common source. As an argument in favor of this conclusion he calls attention to the opinion of French authors (Sarcia *et al.*, 1958) that in the Central Massif, the ore-forming hydrothermal activity related to late Paleozoic intrusions of granitic magma may be traced in Triassic and Lower Jurassic strata. As known, the hydrothermal ore forming solutions may remain for a long time in the so called "fossil water reservoirs".

As a corollary of magmatic origin of ore fluids or as an alternative explanation is the generation of heat and the subsequent regeneration of Late Paleozoic ores as a consequence of geologic evolution of the Earth's crust. The MVT deposits tend to occur at specific stages of such evolution. These stages correspond to the global break-up of plates and the beginning of new geosynclines in the Earth's history. Such turning points in the evolution of the Earth's crust are invariably associated with significant heat flow. The emplacement of the Upper Silesian strata-bound sulfide ores occurred in the Triassic which reflects the Pangean break-up following the Early Permian assembly of Pangea (e.g. Trumpy, 1982; Veevers, 1989). It is thus tempting to interpret the origin of the Upper Silesian strata-bound sulfide ores in terms of global plate reorganization (Przeniosło, 1974; Pafys, 1967; Dżułyński & Sass-Gustkiewicz, 1985).

Summing up, with the present state of knowledge it is difficult to provide reliable evidence concerning the source of base metals. The possibility of a long distance fluid flow from unknown or hypothetical source beds cannot be discarded. However, the source of metal-bearing fluids may well be searched in deeper parts of the crust, below the present Triassic deposits. In a speculative reconstruction of the processes which resulted in the emplacement of strata-bound sulfide ores we arrive at the following tentative formation model. The primary metal-bearing fluids were originally related to the Late Paleozoic igneous activity which gave rise to the polymetallic ores. These ore fluids or ores became remobilized by heat flow during the late Triassic plate-tectonic reorganization and redeposited as strata-bound deposits in the Muschelkalk host strata. During the

Lower Tertiary, the flow of hydrothermal solutions was reactivated and resulted in deposition of economically unimportant, fault-hosted sulphide ore veins. This time, indeed, the faulting was related to final thrusting of the Carpathian nappes. The heat generated by friction of rock masses along the fault surfaces raised the temperature of ground waters and enabled the remobilization of earlier sulfide deposits.

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Streszczenie

KOMENTARZ DO GENEZY GÓRNOŚLĄSKICH ZŁOŻ RUD Zn-Pb W UTWORACH TRIASOWYCH

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W związku z ukazaniem się ostatnio szeregu artykułów dotyczących genezy złóż rud cynku i ołowiu na Górnym Śląsku, w których przypisuje się istotne znaczenie danym pozostającym w sprzeczności z faktami geologicznymi, zabieramy raz jeszcze głos w sprawie ich genezy. Choć po kilkudziesięcioletniej dyskusji już nikt nie kwestionuje poglądu o epigenetycznym i hydrotermalnym pochodzeniu, nadal jeszcze pozostały zagadnienia, co do których poglądy są podzielone. Należą do nich następujące kwestie: – wiek złóż; – stosunek rud do form krasowych i tektoniki; – drogi migracji metalonośnych roztworów oraz mechanizmy ich przemieszczania się i depozycji; – pochodzenie roztworów hydrotermalnych i źródło zawartych w nich metali. Pomimo, że przytoczona dyskusja koncentruje się na poziomo rozprzestrzenionych (strata-bound) złóżach rud występujących w utworach triasowych, wypływające z niej wnioski dotyczą również złóż rud cynku i ołowiu w utworach paleozoicznych, które są z nimi związane genetycznie.

Zmineralizowana część węglanowych skał otaczających złoża zawiera niezliczone pustki o różnicowanej wielkości wskazujące, że procesy rozpuszczania krasowego rozwijały się na każdym etapie rozwoju tych złóż, począwszy od etapu metasomatycznego (proto krasowego) do etapu krasu dojrzałego. W każdym z nich rozpuszczanie krasowe zachodziło równocześnie bądź prawie równocześnie z wytrącaniem się rud, na co jednoznacznie wskazują zmineralizowane brekcje zawałowe i zmineralizowane osady wewnętrzne. Leach i inni (1996), zwracając uwagę na fakt występowania płonnych brekcji zawałowych oraz powołując się na przejawy zastępowania siarczkami ich spoiwa sugerują, że wiele ze zmineralizowanych brekcji zawałowych powstało wskutek selektywnego zastępowania spoiwa starszych płonnych “przed-rud-

nych brekcji”. To z pozoru logiczne rozumowanie nie znajduje poparcia w znanych faktach geologicznych dotyczących rozwoju zjawisk krasowych w tym obszarze.

Powszechnie akceptowany pogląd, że obserwowana w skałach otaczających złoża tektonika odgrywała ważną rolę w tworzeniu się i rozmieszczeniu górnosląskich złóż rud, rozumiany jest często w diametralnie różny sposób. Zdaniem autorów fakty geologiczne dowodzą, że tylko wczesnokimeryjskie uskoki, pokrywające się z uskokami waryscyjskimi mogą być przed- lub syndepozycyjne z rudami. Większość uskoków obserwowanych w złożach, będących rezultatem wczesnotrzeciorzędowej lub neogeńskiej tektoniki, jest jednoznacznie położowa, ponieważ przecina i przemieszcza ciała złożowe. Tektonika ta natomiast spowodowała lokalną regenerację i remobilizację wcześniej zdeponowanych siarczków, które w znikomych ilościach obserwowane są w szczelinach jurajskich wapieni.

Opinie o wieku złóż górnosląskich podzielone są pomiędzy dwie hipotezy: o mineralizacji przedgórnourajskiej bądź trzeciorzędowej związanej z tektoniką alpejską. Ta ostatnia hipoteza znalazła rzekome poparcie w badaniach paleomagnetycznych, których wartość może być jednakże kwestionowana ze względu na brak realistycznej lokalizacji badanych prób oraz sformułowane poniżej zastrzeżenia natury geologicznej. I tak nie daje ona odpowiedzi na następujące pytania: 1 – Jak wyjaśnić transgresywne ułożenie morskich osadów górnourajskich na zerodowanej i skrasowiałej powierzchni dolomitów kruszczońskich zawierających w znacznym stopniu utlenione rudy? 2 – Dlaczego ascenzyjne roztwory mineralizujące nie pozostawiły żadnych śladów mineralizacji w przepuszczalnych utworach batonu i keloweju? 3 – Dlaczego kruszce wytrącały się tylko w wapieniu muszlowym a nie w dobrze uławionych węglanowych osadach jurajskich lub kredowych? 4 – Dlaczego w wapieniach jurajskich czy kredowych nie ma dolomitów kruszczońskich? Przedjurajski wiek okruszczenia wyjaśnia natomiast równoległe do uławicenia rozmieszczenie ciał rudnych. Roztwory dolomityzujące poprzedzające deponację siarczkowych rud, wykorzystując zachowaną wciąż pierwotną porowatość osadów, mogły z łatwością przemieszczać się równoległe do uwarstwienia, zwłaszcza, że w tym czasie osady triasowe nie były jeszcze zaburzone dolnotrzeciorzędowymi i neogeńskimi uskokami.

Rozmieszczenie złóż w utworach triasowych na tle późnowaryscyjskiej tektoniki wyraźnie sugeruje, że ascenzyjne roztwory hydrotermalne deponujące złoża siarczków cynku i ołowiu,

przemieszczały się przez zaburzone tektonicznie dolnokarbońskie i dewońskie skały węglanowe, najprawdopodobniej w obrębie strefy spękań Kraków–Lubliniec (KLFZ) oraz stref uskokowych Tarnowskich Gór (TGFZ) i uskoku Górnosląskiego (USF) przedstawionych na Fig. 1. Wskazują na to zarówno obecność żyłowych skupień rud o takiej samej mineralogii w utworach paleozoicznych jak i fakt występowania największych nagromadzeń rud w utworach triasowych głównie w miejscach gdzie skały podścielające były silnie spękane. Zerodowane paleozoiczne skały tworzyły w przed triasowej topografii, charakterystyczne dla złóż MVT pasmo wysokich wzgórz. Pogrzebane w górnym triasie wzgórza były szczególnie dogodnym miejscem, w którym ascenzyjne roztwory mogły przekraczać niezgodny kontakt skał i rozprzestrzeniać się poziomo w uławionych utworach triasowych.

Pochodzenie roztworów mineralizujących jest przedmiotem domysłów. Ponieważ powstanie tak rozległych złóż wymaga intensywnej i ogromnej objętościowo przepływu roztworów mineralizujących słusne jest rozważenie idei o głębokich “pogrzebanych rezerwuarach”, których gwałtowny drenaż następuje w warunkach uaktywniania się spękań tektonicznych. Wobec przestrzennego związku między skałami magmowymi w paleozoicznym podłożu a okruszczeniem skał triasowych, istniejącego, na wschodnim obrzeżeniu obszaru występowania złóż rud Zn-Pb można przypuszczać również, że okruszczenie tych utworów jest przejawem schyłkowej aktywności stygnącej i zapewne w znacznej mierze zastygłej już waryscyjskiej masy magmowej.

Jako mechanizm przemieszczania roztworów mineralizujących zwoleńnicy trzeciorzędowego wieku złóż proponują nasuwanie się karpaccich płaszczowin – “long-distance lateral fluid flow”. Z przedjurajskim wiekiem złóż rud natomiast spójne pozostają trzy mechanizmy przepływu: – “topography driven flow” z ładu położonego na południe; – “short distance flow” z zalegających w pobliżu oraz podścielających złoża triasowe utworów karbońskich; – przepływ pionowy z hipotetycznego źródła magmowego.

Należy również pamiętać, że złoża MVT powstawały w określonym globalnym stadium rozwoju skorupy ziemskiej. Powstanie górnosląskich złóż, zdaniem autorów, przypadło na okres rozpadu Pangei, ogólnej tensji i tworzenia się głębokich rozłamów. Z takimi zjawiskami wiąże się wzmożony dopływ ciepła, uaktywnienie przepływu roztworów hydrotermalnych jak również możliwa jest remobilizacja wcześniejszych generacji minerałów kruszczońskich.