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Palaeokarstic Zn-Pb ores produced by ascending hydrothermal solutions in Silesian-Cracow district

The following paper presents a general picture of Zn-Pb sulfide ores in Silesian-Cracow region. The ores are interpreted in terms of hydrothermal karst processes.

The authors aim is to present an overall picture of in hydrothermal palaeokarst processes which resulted in the emplacement of Zn-Pb sulfide ores in the Silesian-Cracow region. The following considerations are based chiefly on earlier papers (for references see S. Dżułyński, M. Sass-Gustkiewicz, 1985) but include some new ideas and additional information.

The term „underground karst" is applied to dissolution cavities, cavity fillings and rock disturbances produced by the action of aqueous solutions of any origin, composition and temperature. The disturbances termed „karst tectonics" (J. Balwierz, S. Dżułyński, 1976) result from stress redistribution consequent upon dissolutional removal of rocks and include: collapse breccias, minor gravity faults and sloping of layers towards the areas of maximum dissolution. Karst features produced by the action of hot solution are termed „hydrothermal karst" (J. Kunsky, 1957; G.A. Maksimovich, 1969). The hydrothermal karst structures are similar to those produced by the action of unmineralized meteoric waters but differ in composition of speleothems and in large extent of wall-rock alterations. The speleothems here discussed include chiefly Zn, Pb and Fe sulfides and mineralized internal sediments. The wall-rock alterations include: recrystallization, dolomitization, ankeritization, and granular disaggregation.

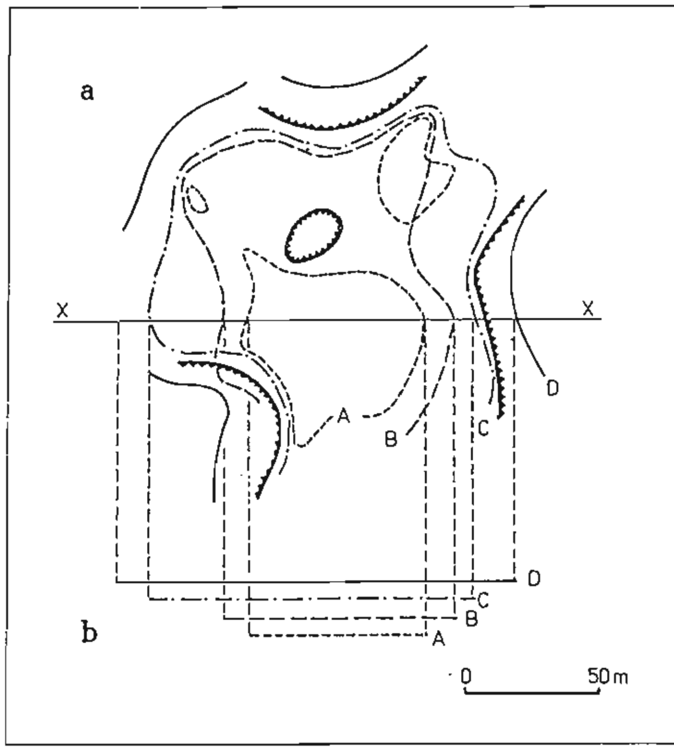

Fig. 1. Horizontal section through collapse breccia showing zonal distribution of various stages of mineralization, indicated from the oldest A, B, C and D respectively (a) and areas occupied by succeeding stages of mineralization along the cross-section line x — x (b); indented line indicates breccia boundary (modified after M.Sass-Gustkiewicz, 1975)

Poziomy przekrój przez brekcję krasowo-zawałową przedstawiający strefowe rozmieszczenie produktów poszczególnych stadiów mineralizacji, oznaczonych odpowiednio od najstarszych A, B, C i D (a) i obszary zajęte przez produkty kolejnych stadiów mineralizacji widziane na linii przekroju x — x (b); linia ząbkowana oznacza zasięg brekcji (zmodyfikowane na podstawie M. Sass-Gustkiewicz, 1975)

The conclusion arrived at is that hydrothermal palaeokarst phenomena played an important role in ore-forming process. This conclusion rests on the following premises (S. Dżułyński, M. Sass-Gustkiewicz, 1985):

— the voids serving as ore receptacles are dissolution and/or dissolution motivated openings;

— the sulfides infilling the voids are hydrothermal ores;

— the voids and the ores in them resulted from the action of the same formative solutions.

1. Dissolution voids which form an integrated system of transmissive channels are, by definition, karst forms. Such integrated system occurs in the ores under consideration. Therefore, the mineralized dissolution voids fall into the category of karst cavities.

The karstic origin of mineralized breccias which are among important ore receptacles is shown by the following features:

a — in plan view, the breccias have irregular, branching patterns (Fig. 1);

b — in vertical cross-sections the breccias occur in the form of irregular nests;

c — the lowermost boundaries of breccias are dissolution surfaces representing the former floors of caverns;

d — these surfaces are covered with mineralized internal sediments;

e — the internal sediments pass upwards into a rubble of angular dolomite blocks;

f — the upper and lateral boundaries of breccias are not sharp and the rubble breccia passes into a network of fractures and sag fissures;

g — in contrast to tectonic breccias, the rock and ore fragments are devoid of slickensided surfaces and tectoglyphs.

The ore breccias tend to occur preferentially along the lower, metasomatic boundaries of the ore-bearing dolomite and are seen to spread laterally and upwards with little or no downward expansion. Progressive roof failure is an important factor promoting the development of rubble breccias. The crackle and mosaic breccias may develop in the absence of sizeable caves through:

— derangement of layers overlying the strata which are subjected to disaggregation;

— simultaneous dissolution along a great number of fractures or other discontinuities („polycentric derangement breccias" — J. Balwierz, S. Dżułyński, 1976).

Moreover, some of the mineralized breccias might have resulted from changes in ore fluid pressure and/or the disrupting force of crystallization.

2. Fluid inclusions indicate deposition temperatures of sulfides ranging from 90 to 135°C (A. Kozłowski et al., 1980). In addition, geologic evidence points to supply of base metals from deep-seated sources. Accordingly, the sulfide incrustations and fillings of karst cavities are of hydrothermal origin.

3. The mineralized breccias resulted from a succession of mineralization and brecciation events whereby successively younger sulfide minerals envelope clastic products of earlier brecciation and mineralization episodes (M. Sass-Gustkiewicz, 1975). The brecciation and mineralization phases were not interrupted by any significant time intervals and were overlapping in time and space. In addition, the breccias, as seen in plan view, show zonal and concentric arrangement of minerals with younger generations covering successively larger areas (Fig. 1). This reflects the lateral growth of the breccia bodies. The above relationships indicate that the ores and their host breccias were produced by the action of essentially the same solutions. These solutions, however, were hydrothermal solutions. Accordingly, the mineralized breccias represent hydrothermal palaeokarst structures. This conclusion applies to the mineralized fractures that protrude from collapse structures and to sag fissures which tend to occur above the breccia bodies.

In addition to mineralized collapse structures that represent mature stage of karst development, one can distinguish initial karst ore bodies. Such ore structures are characterized by subsidence of rocks overlying large but low-ceilinged caves (see Tab. 1).

The recurrent phases of precipitation and brecciation, as well as the morphological and textural diversity of sulfide precipitates, reflect changes in composition, character and hydrodynamic properties of the karst-, and ore-forming fluids. Such changes are related to:

— deep-seated processes, i.e., inherent to origin of ore fluids;

— dissolution-motivated alterations within the evolving karst system (M. Sass-Gustkiewicz, 1985).

Both types of ore structures: the initial and the mature, contain mineralized internal sediments. Although the internal sediments are voluminuously insignificant, their importance lies in the fact that they were previously confused with external sediments and were used as an argument in favour of synsedimentary origin of sulfide ores. The internal sediments include: insoluble residuals of host rocks, disaggregated dolomite grains, clastic fragments of ores and ore-bearing dolomite as well as sulfide precipitates. Finely laminated sphalerite layers in the internal sediments are composed of detrital grains and of crystals precipitated *in situ*. Such mineralized cave deposits show structures that are known to occur in marine and nonmarine surface sediments and include cross-stratification, graded bedding and soft-rock deformations (M. Sass-Gustkiewicz, D. Kobus, in press). The graded bedding might have resulted from subterranean turbidity currents (density currents), initiated by roof collapse of caverns, stirring up clouds of fine bottom sediments. Such clouds were then spreaded laterally in the form of density currents (S. Dżułyński, M. Sass-Gustkiewicz, 1980).

The hydrothermal karst phenomena are commonly associated with the emplacement of metasomatic ores which are an integral part of such phenomena although they may also occur independently of karst processes. The metasomatic sphalerite ores, like other mentioned wall-rock alterations, are product of a slow, non-integrated e.g. dispersed solution transfer. The metasomatic ores commonly show minute and narrow dissolution vugs developed along primary or secondary discontinuities where the velocity of replacing fluids is relatively high and the dissolution may run ahead of deposition (W. Lindgren, 1918). In other words, the voids were formed when the emplacement of neosome lagged behind the dissolution of the host rock. For this reason, it is advisable to interpret the metasomatic deposit as a protokarst stage of the ore body development (M. Sass-Gustkiewicz, in press). In metasomatic ore deposit, the cavity-making process seems to be an integral part of the ore forming process. Where the vugs are solutionally enlarged and interconnected in a system of incipient karst conduits, the metasomatic ores are seen to pass into the initial karst structures.

The non-integrated, slow solution transfer may also bring about the disintegration of the host dolomite i.e., the transformation of hard rocks into a loose mass of grains. In such a mass euhedral sulfide crystals may grow by pushing aside disaggregated particles i.e. by „amoblastesis" (the term introduced by S. Dżułyński, M. Sass-Gustkiewicz, 1985; see also K. Bogacz et al., 1973). The amoblastic sulfide crystals may overgrow relics of hard, non-disaggregated rock, in a manner similar to that observed in crystals coating the walls of empty cavities. Solutional disaggregation goes before or proceeds concurrently with the emplacement of ores. It may also continue after encrustation of still lithified relics of host rock. With the disappearance of relics the incrustations become suspended in a structureless mass of grains. During such pro-

Table 1

Dissolution motivated voids and their relationships to solution transfer

KARST STAGES	EFFECTS OF DISSOLUTION		SOLUTION TRANSFER
	CHEMICAL	MECHANICAL	
PROTO	1. Enlargement of effective porosity 2. Enlargement of sedimentary discontinuities	CRACK POROSITY	NON-INTEGRATED to POORLY INTEGRATED
INITIAL	Formation of low--ceilinged, laterally disposed caves	SUBSIDENCE 1. sag fissures 2. multidirectional fracturing 3. mosaic breccias	POORLY INTEGRATED to INTEGRATED
MATURE	Vertical enlargement of already existing caves	COLLAPSE 1. sag fissures 2. crackle breccias 3. rubble breccias: — self-supported —matrix-supported	INTEGRATED

cesses the incrustations may break into pieces which than may sink down into soft, disaggregated mass of grains. The resulting structures bear a confusing similarity to synsedimentary redeposition structures, notably where the disaggregated host rock has been subjected to recementation and recrystallization.

The metasomatic and amoblastic ores are interpreted as products of the same ascending mineralizing solutions which brought about the appearance of karst receptacles and deposited the ores in initial and mature karst structures.

The observations in all scales point to the conclusion that the cavity-making processes in all the stages of karst development are essentially coeval with the mineralization and that the mineralization is always associated and combined with the appearance of dissolution. It seems that the dissolution is the most important and, in many cases, the dominating process in the formation and shaping of the ore structures. The three distinguished types of ore deposits: proto-, initial- and mature-karst ones generally appear in this succession and commonly are superimposed one upon another (M. Sass-Gustkiewicz, 1985).

Table 1 illustrates the chemical and mechanical effects of dissolutions that are typical of specific stages of karst development. The chemical and mechanical effects of dissolution are closely interrelated and usually the mechanical deformations are the direct products of dissolution. It is proposed that with progressing dissolution the enlarged voids were connected and transformed into transmissive karst conduits. This

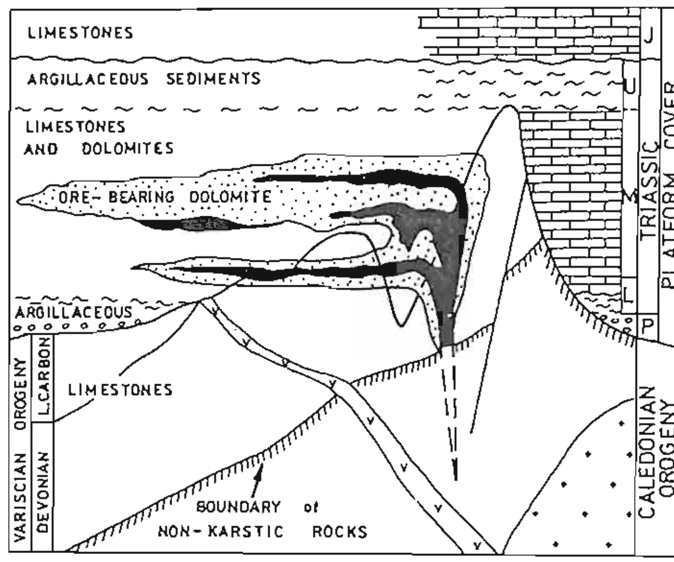

Fig. 2. Scheme of hydrothermal karst system related the structural units of the Silesian-Cracow Zn-Pb ore district (after M. Sass-Gustkiewicz, in press)

+ and v — igneous rocks

Schemat systemu krasowego na tle ogniw strukturalnych śląsko-krakowskiego obszaru rudnego (według M. Sass-Gustkiewicz, w druku)

+ i v — skały magmowe

influenced the solution transfer causing characteristic succession of solution transfer types: from non-integrated in proto-karst stage, throughout poorly integrated in initial stage, to integrated in mature stage of karst development. The ore mesostructures, resembling morphologically the speleothems of the meteorie karst caverns, when examined in relation to the development of ore bodies also point to the same succession of solution transfer changes (M. Sass-Gustkiewicz, 1985). In contrast to the earlier conclusion of M. Sass-Gustkiewicz (1985) who suggested the existence of vadose zone, the new investigations of internal sediments (M. Sass-Gustkiewicz, D. Kobus, in press) seem to deny the presence of vadose stage. It is evidenced by the complete infilling of karst forms by partly uncemented breccias and by the presence of unlithified internal sediments which had to be at least partly eroded by solutions flowing under hydraulic gradient typical of vadose conditions.

All the data presented above indicate that dissolution is the main factor causing the transformation of carbonate host rocks. By creating new voids the dissolution is continuously changing the conditions of the transfer of ore-bearing fluids and, consequently, the character of the transfer itself. There is a good reason to suppose that the changes in character of the solution transfer influenced the emplacement of ores and that these changes are now reflected in the specific types of ore structures observed in all the scales (M. Sass-Gustkiewicz, 1985).

The overall schematic picture of hydrothermal Zn–Pb ores in Silesian–Cracow region can be visualized as follows (Fig.2): the ores in lower part of the rock sequence (Paleozoic carbonates) occur in the form of vertical or subvertical ore bodies containing abundant mineralized breccias (S. Kurek, 1988). Such breccia bodies tend to develop along tectonic fractures of great vertical extent which cut both the pre-Variscan, non-karstic rocks and the Devonian–Lower Carboniferous carbonates (Fig. 2). In these carbonates the walls of fractures show occasionally evidences of dissolution. The breccias contain also mineralized internal sediments. All these breccias show recurrent brecciation and mineralization events. Higher in the sequence the vertical ore bodies grade into horizontally arranged ores emplaced in both Paleozoic carbonates (as can be interpreted from S. Kurek, 1988, p. 397, Fig. 3) and, finally, into the bedding-controlled ores, horizontally disposed, Triassic carbonates. All the ores in both, the Triassic and Paleozoic rocks, are enclosed in the ore-bearing dolomite.

Taking into account all these data, it is suggested that the Zn–Pb sulfide deposits in Paleozoic and Triassic rocks can be interpreted as two branches — vertical and horizontal — of the same hydrothermal karst system (M. Sass-Gustkiewicz, in press). The geometric pattern of this system can be compared with the geometry of endogenic karst envisioned by E. I. Kutyriev et al. (1989).

Accepting the idea that the ore bodies in the Paleozoic and Triassic were formed in one formative event, the vertical breccia bodies may be explained as follows:

— brecciation of non-karstic rocks can be caused by hydraulic fracturing and/or by breaking of wall rocks permeated under high pressure with the onset of dilatancy which is associated with a sudden drop of pressure (see e.g. P. Kents, 1964; W. S. Fyfe et al., 1978);

— brecciation of karstic rocks could result from above mentioned process and can be related to dissolution-motivated karst tectonics.

Summing up, the ascending hydrothermal solutions moved upwards along tectonic fractures in Paleozoic rocks which acted as passageways of ore fluids. In the higher part of rock sequence i.e. in Triassic carbonates (and probably also in the upper part of Paleozoic carbonates), the ascending ore fluids have spread horizontally taking advantage of bedding surfaces and lithologic boundaries and formed horizontally disposed, proto-, initial- and mature-karst structures. The lateral fluid ingress was influenced by the presence of water horizons, impermeable layers and/or by closing or sealing of vertical fractures.

Each karstic model involving the transfer of solutions requires the presence of recharge and discharge areas. In the Silesian–Cracow ore district the input areas can be directly observed whereby output ones are more conjectural. However, because the ores were emplaced below an ancient unconformity, it is probable that the excess of solutions might have reached the Earth surface. In this respect, of great interest are bodies of pure, crystalline limestones reported to occur within non-marine clays in the uppermost Triassic strata (Woźniki Limestone). Such limestones were interpreted as products of springs and might have been precipitated in the discharge areas of hydrothermal solutions (K. Bogacz et al., 1970). It is also suggested that calcium carbonate was released during dolomitization and dissolution of limestones.

The ore mineralization diseussed here oecurred prior to the Jurassic cycle of sedimentation. It is to be noted, however, that Lower Tertiary teetonie movements remobilized some of the ores and brought about the emplacement of galena-dominated hydrothermal ores in vertical struetures.

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PALEOKRASOWE RUDY Zn-Pb — PRODUKT ASCENZYJNYCH ROZTWORÓW HYDROTERMALNYCH W OBSZARZE ŚLĄSKO-KRAKOWSKIM

Streszczenie

O interpretacji zjawisk krasowych, obserwowanych w śląsko-krakowskich złożach rud Zn-Pb, jako hydrotermalnych procesów złożotwórczych (rudy i formy krasowe powstały pod wpływem tych samych roztworów hydrotermalnych), decydują dane wskazujące na równoczesność tworzenia się form krasowych i występujących w nich wysokotemperaturowych siarczków. Obserwowane w złożach sfalerytowe rudy metasomatyczne interpretowane są jako utworzone w stadium protokrasowym, podobnie jak rudy amoblastyczne, w trakcie niezintegrowanego przepływu roztworów zmineralizowanych. Stadia inicjalne i dojrzałe krasu generalnie występują kolejno po stadium protokrasowym. W tabeli 1 przedstawiono efekty chemiczne i mechaniczne krasowego rozpuszczania, które sumując się dają obraz ewolucji dróg migracji roztworów mineralizujących, a co za tym idzie przeobrażeń w ich dynamice. Łącznie ze złożami w utworach dewońskich złoża rud triasowych są interpretowane jako jeden paleokrasowy, ascenzyjny system hydrotermalny, odpowiedzialny za powstanie złóż występujących w formach krasowych.